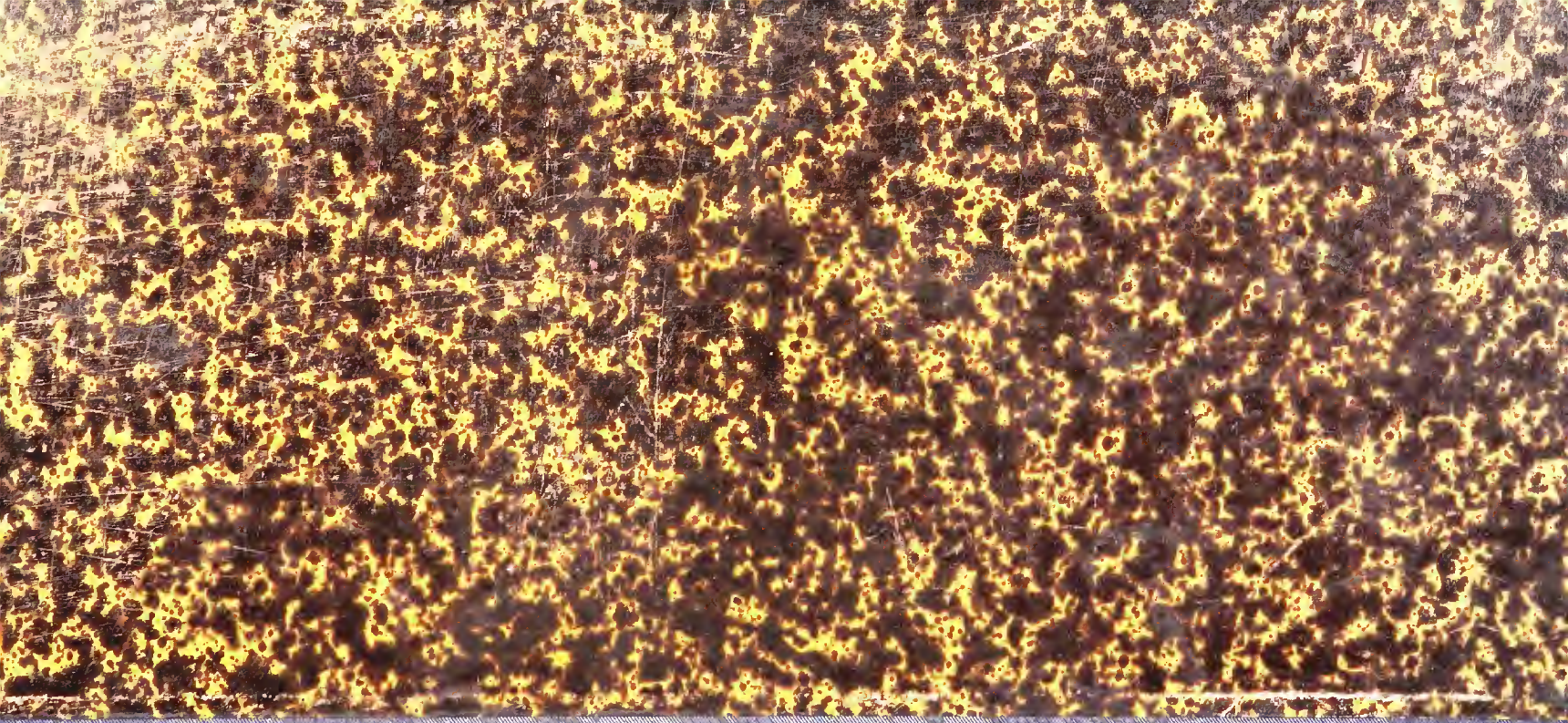

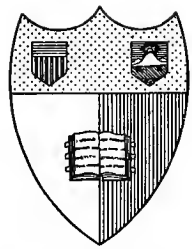

MEMOIRS OF THE GEOLOGICAL SURVEY.

ENGLAND AND WALES.

ON THE MESOZOIC ROCKS

IN SOME OF THE

COAL EXPLORATIONS IN KENT.

BY

G. W. LAMPLUGH, F.R.S.,

AND

F. L. KITCHIN, M.A., Ph.D.

PUBLISHED BY ORDER OF THE LORDS COMMISSIONERS OF HIS MAJESTY'S TREASURY.

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203. BEDFORD	—	9 9	—
229. CARMARTHEN	1 6	1 6	2 0
230. AMMANFORD	1 6	1 6	2 6
231. MERTHYR TYDFIL	1 6	1 6	1 6
232. ABERGAVENNY	1 6	1 6	2 0
246. WEST GOWER	1 6	1 6	0 6
247. SWANSEA	1 6	1 6	2 6
248. PONTYPRIDD	1 6	1 6	1 6
249. NEWPORT (MON.)	1 6	1 6	1 6
254. HENLEY-ON-THAMES	—	1 6	2 0
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263. CARDIFF	1 6	1 6	2 3
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315. SOUTHAMPTON	—	1 6	1 6
316. HAVANT	—	1 6	—
317. CHICHESTER	—	1 6	1 0
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328. DORCHESTER	—	1 6	1 0
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HAND-SPECIMEN OF TOPMOST ATHERFIELD CLAY AT DOVER, WITH BORED CRYPTS OF *PHOLADIDEA* DESCENDING FROM BASE OF SANDGATE BEDS.

$\frac{3}{4}$ Natural size.

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PREFACE.

The explorations for coal in Kent by means of borings and shafts have provided exceptional opportunities of examining the concealed Mesozoic rocks of the County. Accounts of the Coal Measures, so far as those strata have been penetrated, have been published from time to time by geologists officially connected with the exploring companies, but the published descriptions of the overlying strata have been meagre and inadequate.

In view of the additions which were likely to be made to our knowledge of the range and character of the Mesozoic rocks under the south-east of England and the importance of that knowledge as bearing on the prospects of future explorations, it was determined to take advantage of the permission which had been accorded to us by some of the exploring companies to make full examination of the material raised to the surface, on the understanding that our investigations were not extended into the Coal Measures. The present volume is the outcome of that determination.

The investigation was actually commenced in 1897, when Mr. Lamplugh was engaged in collecting material for a memoir on the Lower Cretaceous rocks of England. Subsequently the services of Dr. Kitchin were called in to continue the examination of the strata at Dover as the sinking of the shaft there proceeded, and to pass in critical review the whole of the great collection of fossils which had been made there and at the other explorations.

Besides the sections described in this Memoir several other shafts and boreholes have been made or begun in Kent, but for various reasons it became necessary to confine the published account almost wholly to the four localities, Dover, Brabourne, Pluckley and Penshurst. For the permission to publish the information obtained from these localities we are indebted to Kent Collieries Ltd. We desire also to acknowledge the great assistance which has been rendered us by the engineers formerly in charge of the Dover sinkings, Mr. A. Reid, M.Inst.C.E., F.G.S., and Mr. J. Newton.

The volume falls naturally into two parts, a stratigraphical part (with a historical introduction) by Mr. Lamplugh and a palæontological part by Dr. Kitchin. The stratigraphical part was written more than three years ago, before certain information relating to the Mesozoic rocks of other Kentish borings came to hand. Some of this information is briefly referred to in the palæontological part, by permission of Dr. Malcolm Burr.

The results of the investigation have proved to be of much interest and no little economic importance. The Lower Cretaceous rocks in their underground development show considerable variations from their development in their neighbouring outcrops. At Dover the palæontological evidence establishes the presence

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of an unconformity between the Hastings Beds and the Kimmeridge Clay, only the lower part of the clay being represented. To the west, on the other hand, the Upper Kimmeridge Clay is so largely developed that the Penshurst Boring failed to reach its base. This development is in part due to a westward augmentation of sediment which is shared by all the Jurassic and Lower Cretaceous formations, and which indicates a region of long and continuous depression. The depression, however, ceased before the Upper Cretaceous rocks were deposited, and upon the region affected by it the Wealden anticline has since been superimposed. To the north-east the proximity of a shore-line is evidenced in the peculiar characters observable in several of the Jurassic rocks.

J. J. H. TEALL,
Director.

Geological Survey Office,
28, Jermyn Street, London,
16th November, 1911.

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By F. L. KITCHIN.

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ON THE MESOZOIC ROCKS IN SOME OF THE COAL EXPLORATIONS IN KENT.

CHAPTER I.

INTRODUCTION.

Fourteen years ago, when the exploration for coal in Kent had just entered upon its active stage by the commencement of shaft-sinking at Dover, one of the authors of this memoir was about to begin the revision of the Wealden district, and was also instructed to collect information for a general memoir on the Lower Cretaceous rocks of England. It was perceived that in both respects the information to be gained from the Kentish enterprises was likely to be of great consequence, and steps were therefore taken to investigate the deep sections while the workings were in progress. Through the courtesy of the officials of the companies at that time responsible for the undertakings, the requisite facilities were afforded, and the investigation was begun at the Dover shafts early in 1897. Afterwards, when the field of the commercial operations was enlarged, there arose difficulties owing to the attitude of some of the new companies, so that it was found impracticable to include all the borings within the scope of the investigation. In the event, the field-work was confined to four localities, viz., the Dover shafts, the boring at Brabourne, that at Pluckley, and that at Penshurst. These places range approximately along an east-west line of 45 miles, as shown on the sketch map (Fig. 1, p. 2).

Our object in this memoir is to place on record the results of our personal examination into the characters of the Mesozoic rocks penetrated at the above-mentioned four places, and to discuss the bearing of the new information upon the general stratigraphy of these rocks in the South of England. In many respects both the description and the discussion must remain for the present incomplete, since we shall confine ourselves almost wholly to the facts which have come under our personal observation, with incidental reference only to the results of other borings that were not accessible to us. As the explorations are still in progress at several places, and as the sinking of the Dover shafts is not yet finished, there is every probability that fuller data will be available in the future. But many years have passed since we made the major portion of our observations, and for various reasons we are not likely to be able to advance the investigation under existing conditions. Hence it has been deemed advisable that the present digest should now be published.

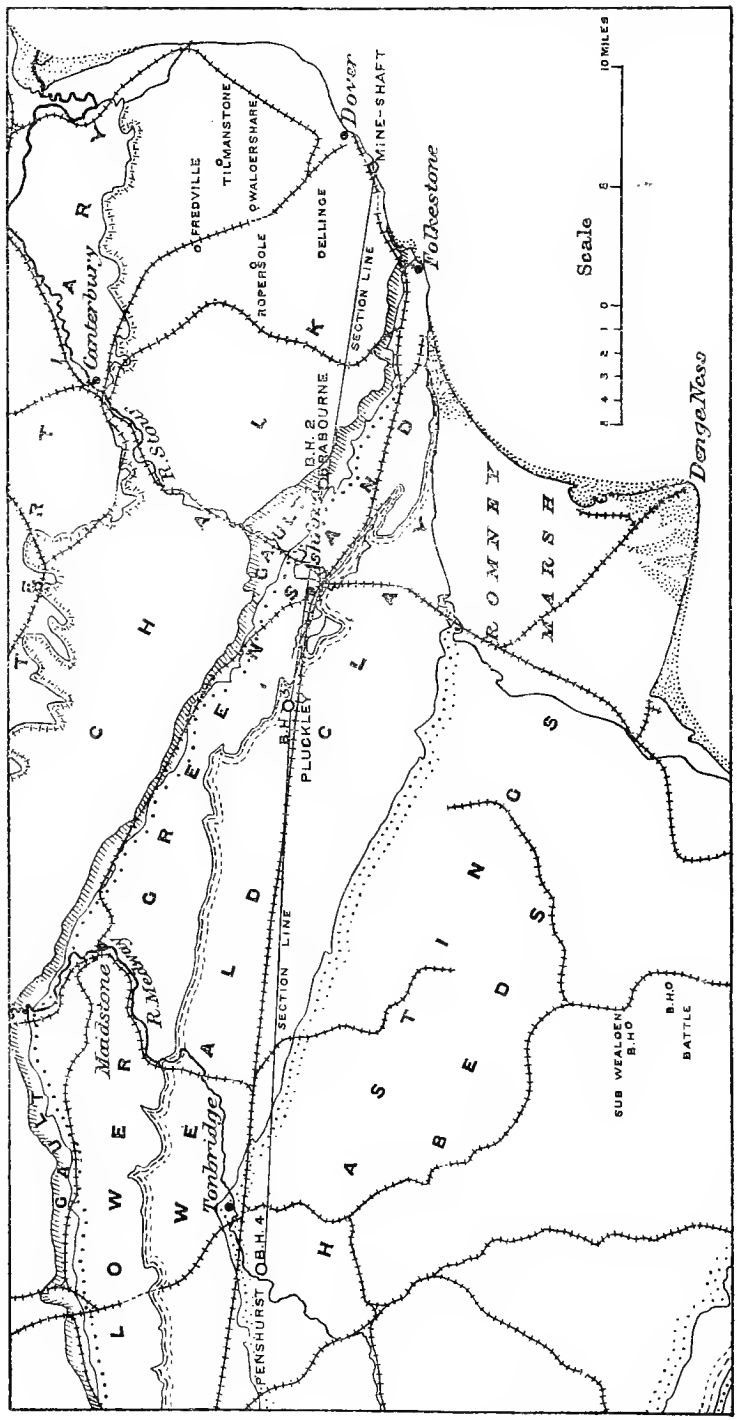


FIG. 1.—GEOLOGICAL SKETCH-MAP, SHOWING THE POSITION OF THE BORINGS, ETC., AND OF THE LINE OF SECTION ILLUSTRATED IN PLATE IV. B.H. = Bore Hole. The shaded lines mark the boundaries of formations at the surface.

Except for a few notes on the Palæozoic rock of doubtful age reached in the Brabourne boring, we have purposely confined ourselves to the Mesozoic rocks. The deep-seated Coal Measures, their probable extent and their tectonic relations, have been fully dealt with in numerous papers by Prof. W. Boyd Dawkins, the late R. Etheridge, Mr. W. Whitaker, and others[1]. The practical object of the explorations will not, therefore, be directly discussed; but as it is mainly upon the thickness and character of the overlying rocks that the success of the colliery enterprises in Kent will depend, all information regarding these rocks has its practical side.

Short accounts of the four sections to be described have already been published—that of the preliminary boring at Dover, by Prof. W Boyd Dawkins[2] and by Messrs. Brady, Simpson, and Griffith[3]; one of the Dover shafts, by the late R. Etheridge[4]; of the Brabourne and Pluckley borings, by Etheridge[5]; and of the Penshurst boring, by Prof. Dawkins[6]. These accounts, while sufficient for the main purpose of showing the thickness of the deposits above the Palæozoic floor, have been too meagre in detail to be satisfactory to the student of the Mesozoic rocks[7].

Our descriptions and classification will be found to differ at some points from these previously published accounts. In most cases it will be unnecessary for us to call particular attention to these points of discrepancy or further to refer to them.

It is frequently difficult for the geologist himself to convey in words a correct impression of the ill-defined characters of rocks of mixed composition, and when the task devolves upon the workman it is inevitable that the journal of the boring will be frequently misleading, and can only be interpreted by an actual examination of the cores. Thus it often happens that some individual bed of no geological consequence is given undue prominence in the record, while others that are of high importance have been passed without mention. For this reason the following descriptions are based as far as possible on our own observations,

---

[1] References to most of this literature will be found in the following publications: W. Boyd Dawkins, "On the history of the discovery of the South-eastern Coalfield," *Trans. Manchester Geol. Soc.*, vol. xxv. (1897), pt. vi., pp. 155–60, and in "Minutes of Evidence," *Final Rep. Roy. Commission on Coal Supplies*, pt. x. (1905), pp. 26–41; W. Taylor, "On the probability of finding Coal in the South-east of England" [*compiled from previous authors*], Reigate, 1886 (*? privately printed*); W. Whitaker, "The Water Supply of Kent," *Mem. Geol. Surv.*, 1908 (bibliography at pp. 220, 364–5).

[2] *Trans. Manchester Geol. Soc.*, vol. xxii. (1894), pp. 489–93 (and in other papers).

[3] *Trans. Inst. Mining Eng.*, vol. xi. (1896), pp. 540–551.

[4] See *Final Rep. Roy. Commission on Coal Supplies*, pt. ix. (1905), pp. 46–7.

[5] *Rep. British Assoc. for 1899* (1900), p. 733; and *Final Rep. Roy. Comm. Coal Supplies*, pt. ix., p. 48, and pt. x., p. 30.

[6] *Final Rep. Roy. Comm. Coal Supplies*, pt. x. (1905), p. 30; also in fuller detail in "The Water Supply of Kent," *Mem. Geol. Surv.*, 1908, pp. 231–3. The memoir last quoted contains records of most of the Kentish deep borings, with notes on the sections by W. Whitaker.

[7] We believe that it was the intention of the late R. Etheridge, who acted as geological adviser to the Companies working at Dover, Brabourne and Pluckley, to publish eventually a detailed description of the sections of these places. Unfortunately he did not live to fulfil his intention.

and we have discarded the borers' records so far as their verbal descriptions are concerned, abstracting from them only the depth and thickness of the strata.

The palæontological work which forms the second part of the memoir makes a considerable advance upon our previous knowledge of the concealed Mesozoic formations, but is not exhaustive even for the material already collected. It contains such results as could be attained by one of us in the time available for the examination of the specimens.

In the next four chapters the four sections are separately described in the downward order of the formations. The sixth chapter contains a summary of the stratigraphy, dealt with in upward succession; and in the seventh, which completes the stratigraphical part of the work, the structural relations of the rocks over the whole area covered by the borings are discussed and some general deductions recorded.

The palæontological results are given independently in the last six chapters, which follow the general order and arrangement adopted in the stratigraphical part. In these later chapters will be found fuller evidence for the classification stated in the earlier part; they were not completed until some time after the stratigraphical account, and circumstances have been unfavourable for more closely interweaving the two portions, though some advantage might have accrued from it.

PART I.—STRATIGRAPHICAL DESCRIPTIONS.

By G. W. Lamplugh.

CHAPTER II.

THE DOVER SECTION.

General Notes.—The operations at Dover afforded us by far the best opportunity for the investigation of the concealed Mesozoic rocks, as the quantity of excavated material was sufficient in most cases to show clearly the lithological composition of the formations represented and to yield a fair knowledge of their fossil contents. The site of the workings is on the great undercliff of fallen chalk at the south-western end of the railway tunnel under Shakespere Cliff—two miles south-west of Dover. In 1897, when our examination began, two shafts were being sunk on this undercliff—to be referred to respectively as No. 1 and No. 2—at a distance of 138 feet apart, starting from a surface-level of 44 feet above high-water of ordinary spring tides.

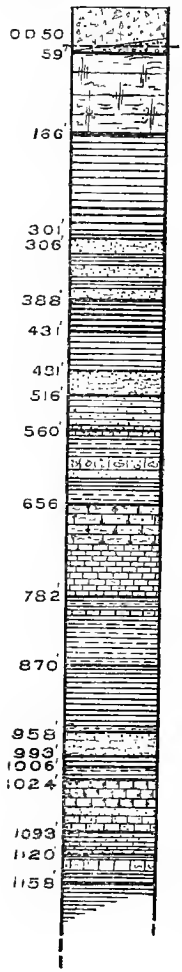
Owing to engineering difficulties, the more westerly shaft, No. 1, was abandoned after it had been sunk to over 500 feet and had entered the Kimmeridge Clay. The base of the Gault had been reached in this shaft before our first visit, but during 1897 we were able, by frequent examination of the tip-heap as the sinking went on, and by occasional descents of the shaft, to study the section of the Lower Greensand and Wealden rocks.

The No. 2 Shaft has been carried down into the Coal Measures, and has yielded the chief part of the information on which the following descriptions are based. In this case also we did not examine the sinking until the base of the Gault was reached; but during 1898-9, while the shaft was being carried through the strata between the Gault and the Corallian rocks, one of us made frequent visits to the workings; and his visits were repeated, though with longer intervals, until his removal from the district in the spring of 1901, by which time the base of the Oxfordian had been reached. The field work was then taken up by the second author, and continued until the sinking was arrested near the base of the Oolites, in the summer of that year, by engineering difficulties. The method adopted later for penetrating the remaining 75 feet of Oolite and Lias in the shaft did not produce material favourable for geological examination, but by the courtesy of the Company and of their geological adviser, the late R. Etheridge, we were permitted to examine and collect from the cores of a pioneer boring, 10 inches in diameter, which was put down from the bottom of the shaft. It is from these cores that our information regarding the lowest part of the Jurassic rocks has been obtained.

A third shaft (No. 3) is being sunk at a distance of 143 feet to the east of No. 2, exactly over the original deep boring. During 1898-9 we obtained some further information from this

FIG. 2.—DOVER: SUMMARISED SECTION TO THE BASE OF THE MESOZOIC ROCKS.

Scale: 1 inch = 250 feet.



	Thickness. Feet.	
Chalk-talus	40 to 47	Recent.
Pebble-beach	½ „ 19	
Chalk (incomplete at top) and Chloritic Marl	107	Upper Cretaceous.
Gault	135	
Folkestone Beds with Mammillatus band; details, at p. 5	5	Lower Cretaceous.
Sandgate Beds; details, at p. 11	82	
Atherfield Clay; „ „ 13	43	
Weald Clay; „ „ 15	50	
Hastings Beds; „ „ 16	35	
Kimmeridgian Beds (lower part only); details, at p. 22	44	Upper Oolite.
Upper Corallian Beds, with iron ore; „ „ 22	96	Middle Oolite.
Corallian limestones; details, at p. 23	126	
Lower Corallian Beds; „ „ 25	88	
Oxford Clay; details, at p. 26	88	
Kellaways Rock; „ „ 27	35	
Cornbrash; „ „ 28	13	
Forest Marble Series; details, at p. 28	18	Lower Oolite.
Great Oolite limestones; „ „ 29	69	
? Inferior Oolite sands; „ „ 30	27	
Upper (6 ft.), Middle ? (16 ft.), and Lower (16 ft.) Lias; details at p. 31	38	Lias.
Coal Measures		Carboniferous.

shaft respecting the beds between the base of the Gault and the base of the Kimmeridge Clay, but we have not followed its later developments.

There is a difference of a few feet in the depths at which the same formation was struck in the different shafts owing to a slight dip of the beds and to irregularities in some of the junctions. We have adopted the measurements obtained from the No. 2 Shaft as our standard; and as the odd inches, while giving an unwarranted air of exactness to the record, are hardly of consequence except where some important bed is less than a foot in thickness, we have in most cases given the figures in terms only of the nearest foot.

The complete section down to the Coal Measures is shown in Fig. 2. We will now deal with the separate formations in their downward order.

Upper Cretaceous.

Our personal knowledge of the beds above the base of the Gault is confined to the information supplied to us by the engineers, along with the results of a casual inspection of some of the material from the lower part of the Gault in the tip-heaps. In the section compiled from the papers of the late R. Etheridge and published in the Report of the Royal Commission on Coal Supplies (pt. ix., p. 46), the following thicknesses were assigned to these strata :—

Strata to Base of Gault, No. 1 Pit, Dover.

		Thickness.		Depth from surface.	
		Ft.	In.	Ft.	In.
	Loose chalk-talus	40			
	Beach	18	11	58	11
Chalk.	Chalk	99	6		
106 ft. 10 in.	Chloritic marl	7	4	165	9
Gault	Grey clay, with fossils ...	97	2		
135 ft. 7 in.	Clay	38	5	301	4

In the upper part of No. 2 Shaft the thickness of the chalk-talus was 6 or 7 feet greater than the above, and that of the underlying recent beach was reduced to a few inches only—a result of the huge fall which has formed the undercliff.

The Gault is about 35 feet thicker than the thickness assigned to it where it comes to the surface in East Wear Bay near Folkestone, three miles farther westward. This difference may arise in part from an under-estimate of its measurement at its slipped outcrop, but is likely to denote some real increase eastward, as it is shown by the middle and lower portions of the formation, which are adequately exposed in the cliff at Copt Point. It is significant of an important change at this stage in the geological conditions of the south-east of England. Practically all the earlier Mesozoic formations in the sections show a decreasing thickness eastward, the Gault being the only bulky deposit in which this condition is reversed.

From the engineers' particulars of No. 1 and No. 2 Shafts we learn that they recognised four divisions in the Gault—an

upper light-coloured bed, about 60 feet thick; an "*Inoceramus*-bed," 30 to 40 feet; a lower dark clay, 34 feet; and a basement bed of dark sandy clay with phosphatic nodules and a layer of pyrites, 12 feet. The upper bed clearly falls within the Folkestone Upper Gault of F. G. H. Price's classification[1], which division should probably also include part of the "*Inoceramus*-bed." Judging from the specimens shown to us, we should describe the "*Inoceramus*-bed" as a pale hard homogeneous marl, crowded with the casts of large examples of *Inoceramus concentricus*. The nodular junction-bed, VIII. of Price's Folkestone section, between the Upper and Lower Gault, does not appear to have been noticed in the Dover workings, and is probably absent. Price pointed out that at East Wear Bay this bed, with its eroded phosphatised casts of Lower Gault fossils and its barrier-like limitation to the range of numerous species both from above and below, probably signified a long pause in the sedimentation, and might be equivalent to a considerable thickness of clay elsewhere[2]. This supposition seems to be sustained by the Dover section, where the thick "*Inoceramus*-bed"—apparently unrecognisable at Folkestone—may represent the expansion of the 10-inch nodular junction-bed into its equivalent of continuously deposited clay. We regret that, as the Gault was not included within the scope of our earlier investigations, we can give no further evidence with respect to this point. It might perhaps have been settled by the zonal collection of the fossils from the shafts; but we noticed that the Gault at Dover appeared to be less rich in fossils than are the corresponding beds at Folkestone.

The Lower Gault clay, even if we exclude any portion of the "*Inoceramus*-bed," is at least 20 feet thicker at Dover than at Folkestone. Its basement-bed, however, participates in the eastward attenuation which is so persistently characteristic of all the underlying formations. We devoted particular attention to this basement-bed because of its close association with the top of the Lower Greensand. It is dealt with under the next heading.

Base of the Gault: the Zone of *Douvilleiceras mammillatum*: and the top of the Lower Greensand.

The pyritous band regarded by Price as the base of the Gault at East Wear Bay was found also in the Dover shafts; but the bed immediately below it, which forms the zone of *Douvilleiceras mammillatum*, was somewhat different in composition from its equivalent in the Copt Point section. At the latter locality, as described by one of us in a previous publication[3], there is 2½ feet of somewhat clayey greensand between the pyritous band and the bed of coarse gritty material which contains the characteristic

[1] *Quart. Journ. Geol. Soc.*, vol. xxx. (1874), pp. 342–68; and "The Gault," (privately printed, London, 1879).

[2] "The Gault," *op. cit.*, p. 9.

[3] A. J. Jukes-Browne and W. Hill "The Cretaceous Rocks of Britain; Vol. I., The Gault and Upper Greensand of England," *Mem. Geol. Surv.*, 1900, pp. 73–4.

fossils, mostly phosphatised, of the Mammillatus Zone; and all the beds below the pyritous bed are allied lithologically with the Lower Greensand series. At Dover, however, the Mammillatus Zone is represented by a foot or two of dark sandy clay, dappled with greensand and sprinkled with small phosphatic nodules, which looks more like the Gault immediately above the band of pyrites than like the gritty Greensand below. This section, therefore, tends in favour of the view held by the French geologists and endorsed by Mr. A. J. Jukes-Browne that the Mammillatus Beds should be classed with the Gault and not with the Lower Greensand, though it is otherwise with the Folkestone section. In Northern France the zone in some places attains a thickness of 30 feet or more, occasionally swelling to 50-60 feet[1], and the conclusion to be drawn from its own individualised fauna and from the wide difference between the faunas above and below it, is that the zone represents a considerable period of time which, in the English sections, is marked only by a highly condensed stratum. It will be shown in the sequel that the Dover section is peculiarly rich in condensed strata of this kind, and that its most remarkable feature is the vast range of Mesozoic time represented in a comparatively small column of material.

The stratum immediately below the sandy glauconitic clay of the Mammillatus Zone affords another striking example of sharp attenuation, as the 3 or 4 ft. of coarse sand and hard lime-cemented grit appear to represent the whole Folkestone Beds of the Lower Greensand, which have a thickness of some 60 feet at their outcrop three miles distant. We had ample opportunity for studying this stratum in the three shafts and in a level which was driven along it between the No. 2 and No. 3 shafts. The section exposed at the pump-house in the level, examined by one of us in 1898, was as follows: —

		Thickness.	Depth from surface. Feet.
Mammillatus Zone.	Dark green sandy clay, with small nodules, dappled and seamed with greensand	about 1½ ft. seen.	... 303
Folkestone Beds.	Rock-band of irregular calcareous concretionary masses of coarse grit with glauconite, shell-fragments, &c.; the separate masses ranging from 1 to 3 ft. in thickness and up to several yards in circumference; embedded in incoherent greensand mixed below with much clay	3 to 4 ft.	... 306
Sandgate Beds. (*see* p. 11.)	Dark loamy clay, silt and sand continuing to depth of	...6 to 7 ft. seen, ...	388

The rock-band, fortunately represented by abundant material on the tip-heaps, was of peculiar interest in many respects. While essentially similar in structure to the concretionary calcareous grits of the Folkestone Beds in the cliff-section west of Copt Point, its aspect was very different owing to the brilliantly fresh condition of its glauconite, coarser grain, abundant nodules of brown

[1] A. J. Jukes-Browne, *op. cit.*, pp. 43–4.

phosphate, and the extraordiuary range of variability of the contiguous masses. Not only did the material vary in different shafts, but it also showed great changes within the area of a single shaft, and appeared to include all the varieties that are distributed through the whole series at the Folkestone outcrop. Some of the blocks brought to the surface were composed of coarse grit, full of small smooth pebbles of quartz and lydite from $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter, along with dark rolled lumps of phosphate 1 to 2 inches in diameter, and a little glauconite, the whole very firmly cemented by crystalline calcite; others were made up of crumbled fragments of shell, with quartz-grains and some glauconite, forming a hard lumachelle; others were brilliant green grits of medium texture, rich in intermingled calcite and glauconite; and others were of a softer stone of very dark green colour with nests of small black pebbles and a great abundance of glauconite. Often, also, the different varieties interpenetrated each other in the same block by long cylindrical ramifications that looked like the filled-in cavities of boring shells and other organisms; and in similar fashion the gritty material was entangled downwards with the dark muddy deposits on which it rested. The general arrangement is evidently an intensified form of the patchy segregation which may be seen in exposures of the top of the Folkestone Beds on the west shore of East Wear Bay. The structure may be assigned to the influence of currents upon sediments that were cemented in patches here and there by concretionary bonds, as on the present sea-floor off the coast of Ceylon[1], while the loose material was winnowed to and fro until held by a fresh patch of induration. Analogous structures have been observed by one of us in beds of about the same age at the top of the Lower Greensand in Bedfordshire[2], and at other places, but nowhere in such perfection as in the present case.

The induration appeared in some places to extend through practically the whole thickness of the sandy bed (3 or 4 ft.), but oftener it was developed mainly in the uppermost 1 or $1\frac{1}{2}$ ft., where it formed large tabular masses nearly in touch with each other, with smaller detached masses in the sand at a slightly lower level. Although the bed was full of comminuted fragments of shells and other organisms, it contained hardly any identifiable fossils, except a small *Pecten* (*see* p. 102). The glauconitic sandy clay immediately above it held many fossils mostly in the condition of phosphatised casts, which are tabulated and described in the second part of this memoir (p. 100). They establish our reference of this bed to the zone of *Douvilleiceras mammillatum*.

In concentrated deposits of this type, marking the passage of long periods of time, it is frequently difficult to define the conventional boundaries of formations; nor in this case does it seem to us to be of much consequence whether the Mammillatus Beds are regarded as the lowermost portion of the Upper Cretaceous or as the uppermost portion of the Lower Cretaceous.

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[1] J. Lomas, "On Sea-bottoms and Calcretes," pp. 147–162, in *Rep. on the Pearl Oyster Fisheries of the Gulf of Manaar*, by W. A. Herdman, F.R.S. Published by the Royal Soc., 1903.

[2] G. W. Lamplugh and J. F. Walker "On a fossiliferous band . . . . near Leighton Buzzard," *Quart. Journ. Geol. Soc.*, vol. lix. (1903), 240–3.

Sandgate Beds.

Below the condensed representative of the Folkestone Beds the shaft passed through a mass of strata from 75 to 82 feet thick, which preserved a homogeneous lithological character throughout, in spite of constant minor variation, and were very similar in composition to the Sandgate Beds of the outcrop at Folkestone, with which they also agree exactly in thickness.

These beds, which we examined at intervals in the shafts as well as in the excavated material at the surface, consisted mainly of very dark muddy glauconitic sand, interspersed with dull black or brown clay, sometimes in laminæ and sometimes in thick bands, and with thin irregular streaks and seams of dirty grey silt or fine sand. Some of the clayey bands contained much pyrites, frequently encrusting lumps of fossil wood. The muddy greensand here and there held a few lamellibranchs, chiefly thick-shelled *Meretrix*, *Astarte*, *Pholadomya*, and small *Pecten*. The shells were generally perfect, but in a soft white crumbling condition, which rendered them difficult to collect. On the whole, however, fossils were scarce both in numbers and in species, and evidently give an inadequate idea of the marine life of the period, all except the least perishable remains having vanished. Where sandy and clayey layers were interlaminated they were curiously mingled by ramifying worm-like markings and by larger round or oval tubes, evidently formed by burrowing organisms, the pale silty material in these burrows sometimes containing a few smooth shining grains of coarse grit. The clayey bands frequently showed bright slickensides along planes of slipping, sometimes arranged in close-set parallel lines like strain-slip fracture, this structure being probably due to slight movements set up during consolidation. The engineers' record of No. 3 Shaft mentions a 9-inch band of hard greensand stone in these beds at a depth of 368 feet; it was probably a solitary concretion, as we saw no stone-band in these beds in the other shafts, nor could we find anything in the section to match either the ' Kentish rag ' or the ' hassock ' of the Hythe Beds.

This absence of deposits comparable with the Hythe Beds is one of the many unexpected features of the Dover section. At their outcrop west of Folkestone the Hythe Beds consist of hard sandy limestones (Kentish rag) with alternations of firm glauconitic sand-rock (hassock), having a thickness of about 60 feet and yielding a well-defined assemblage of fossils. From the coast at Hythe they extend inland westward for about 50 miles without much change of type, but increasing in thickness to 160-180 feet. Still thickening, though now becoming more sandy and less coherent, they continue westward for some 40 miles further, right round the western end of the Weald, and then swing eastward, and are traceable in Sussex for at least 25 miles along the southern side of the great anticline, regaining in this tract their Kentish characters. Yet, despite this prolonged and unbroken range of outcrop, the division appears to be unrepresented or to have lost its individuality at Dover, only seven miles north-east from where it makes a brave show at the surface; while at Brabourne, as we shall presently see, its disappearance

is brought within still narrower limits. The Sandgate Beds, on the other hand, which in the outcrop constitute the most impersistent and most variable of the Lower Greensand divisions, maintain their identity and full thickness underground both at Dover and at Brabourne.

It is, of course, possible either that the Hythe Beds may have passed laterally into the deposits of the Sandgate type above described, or that they may once have existed and have been swept away by intraformational erosion. For the first supposition we saw no evidence; but some support for the second may be found in the conditions at the base of the beds now under consideration.

In the Dover section these beds of the Sandgate type rested sharply upon a firm grey marly clay, full of marine fossils, which proved to be the Atherfield Clay. The junction was sharply defined by a basement bed of the upper series, in the form of an irregular patchy layer of coarse loamy greensand, probably nowhere more than a few inches thick, sprinkled with smooth polished lydites, large quartz grains, bits of brown phosphate, and small detached fragments of the underlying clay. The biggest pebble we saw *in situ* in this material was a rounded fragment of black grit having a diameter of only ¾ inch, but one of much larger size was found by the workmen—a very smooth oval pebble of quartz measuring 3 inches by 4 inches. There is reason to believe, however, that isolated pebbles of this kind, embedded sporadically in deposits of relatively fine texture, may have been transported in the stomachs of saurians[1]; and certainly in this case, as in others which have come under our notice, the pebble was so much larger than the material with which it was associated that some such accidental means of introduction seemed probable.

The coarse greensand contained many large pectens and a few other shells, poorly preserved. Numerous round crypts, of 1 to 3 inches in depth, in the top of the underlying Atherfield Clay were filled with the dark gritty greensand, and still contained at the bottom the shells of *Pholadidea* (probably of an undescribed species) that made the borings (*see* pp. 102-5). The contrast in colour between the crypts of dark greensand and the pale grey clay which forms their matrix, adds to the attractiveness of the specimens obtained at this level. Plate I. (*front.*) is from a photograph of a hand-specimen showing this junction, with traces of the shells in their crypts.

Clearly there has been here at least a long pause in the sedimentation, if not actual erosion, for when bored by the pholadids the clay must have been well-set to permit such sharply cut crypts, and the condition of the fossil-casts near the top of the clay further indicates that it was firmly consolidated before the overlying deposit began to accumulate. But the Atherfield Clay is fairly represented, and it is unlikely that it was ever much thicker. It is very improbable that the Hythe Beds should have been deposited and afterwards exactly removed by denudation,

[1] W. H. Wickes, "The Rhætic Bone Beds," *Proc. Bristol Nat. Soc.*, new series, vol. x. pt. iii. (1904), pp. 212–27; and "Pebble-swallowing Animals (A Sequel to the Rhætic Bone Beds)," *ibid.* 4th ser., vol. ii. (1908), pp. 25–31. These papers contain references to an extensive earlier literature of the subject.

while the Atherfield Clay remained intact though so much less fitted to withstand erosion. Therefore, taking these factors into consideration, we prefer to the opinion that in the layer of gritty and phosphatic greensand we have an intensified example of the condensation of sediments under strong current-action already illustrated in the case of the Folkestone Beds, and that although the Dover area remained beneath the sea during the accumulation of the Hythe Beds, the conditions were such that permanent sedimentation was not possible upon it.

Atherfield Clay.

So little had been hitherto known of the Atherfield Clay in Kent, or indeed in any part of the Wealden district, owing to the rarity and inadequacy of the exposures along its outcrop and the difficulty, in the absence of exposures, in distinguishing it from the underlying Weald Clay, that the vertical sections through it in the Dover shafts afforded a particularly welcome opportunity, of which we availed ourselves to the utmost. It follows that our palæontological and other material collected from this formation is fuller than from any other portion of the section.

The deposit has a thickness of 43 feet, which is 6 feet less than the thickness assigned to it at Hythe, the nearest point of its outcrop, but much more than its supposed thickness in other parts of Kent[1]. The following descriptive details are based on the material examined on the three tip-heaps, and on an inspection in one of the shafts:—

Section of the Atherfield Clay, Dover.

	Thickness. Feet.	Depth from surface. Feet.
Pale tough greenish-grey clay, probably decolorized, perforated by molluscan-borings as above described, with casts of ammonites and other fossils, and small pale brown nodules	1	... 389
Banded marly clays, in alternating tints of pale and dark bluish-grey, brownish-grey, and brown, mostly smooth and unctuous-feeling, but with some darker layers mottled with silty and sandy streaks. Fossils abundant	23	
Firm brown banded clay or marl with small pale brown concretions, and many fossils, particularly ammonites (*Hoplites deshayesi*)	7	
Smooth blue-black unctuous clay, crowded with *Pinna robinaldina;* and with many small *Exogyrae* at base: = "*Pinna*-bed"	1 to 2	
Firm marly clay of rich chocolate colour, with pale brown nodules, fauna varied and abundant, included a band of small crushed echinoderms, but cephalopods rarer	9	
Unctuous dark blue clay (like that of the "*Pinna*-bed") with a thin irregular seam of sandy grit with lydites and brown phosphatic fragments like crumbs of bone, &c.	1	
Resting tightly on, and interlocked with, a corroded deeply pitted surface of Weald Clay at (*see* p. 15).	...	... 431

[1] W. Topley, "Geology of the Weald," *Mem. Geol. Surv.*, 1875, pp. 112–14.

In its fine smooth texture, homogeneous composition, and lack of glauconite, the Atherfield Clay is very different from the overlying greensands, and has evidently been deposited in quieter waters on a bottom well sheltered from the impact of currents. It affords a further example of the unexpected persistence eastward, in full strength, of a deposit which has a comparatively feeble and irregular development in the Wealden outcrop.

The top of the clay appeared to have been decolorised for a foot or so by the influence of the greensand above it, and the top beds had also been slightly disturbed and crushed, as shown by the presence of slickensided surfaces and by the flattening and sideway displacement of some of the pholas-crypts. Slight distortion of this kind was conspicuous in strata of laminated character at several horizons in the Dover section and in all the Kentish deep borings; it is probably the result of the differential shrinkage of the beds during their consolidation under the increasing pressure of the superincumbent sediments[1].

The rich brown tint of a considerable portion of the Atherfield Clay is noteworthy, as it is frequently observable at the outcrop of the clay, and its presence at this depth proves it to be original and not due to weathering. The beds contained very little pyrites, though a few of the smaller ammonites and other shells were filled with it. Most of the clay was calcareous, and possessed a massive marly structure, quite free from any shaly tendency; hence it lifted in big blocks having a subconchoidal fracture. It resembled fullers' earth in its readiness to disintegrate and crumble down when dropped in small lumps into water. The pale-crusted brown nodules, usually about the size of a walnut, which occurred irregularly sprinkled throughout the clay, afforded illustrations of every stage of concretionary growth. Sometimes they possessed a hard black core, probably rich in phosphate, which passed outward gradually into pale material softer than the surrounding clay; and occasionally a faint radial structure, denoting incipient segregation, was visible in the clay for 2 or 3 inches beyond the actual circumference of the nodule. Toward the top of the formation the nodules were larger and more oval, ranging up to 4 or 5 inches in length; and some of these had the long axis vertical, like miniature 'paramoudra.'

Fossils were abundant all through the deposit, but were clustered most thickly in definite bands; of which the "*Pinna*-bed" was the best example, as it was strongly distinguished both lithologically and palæontologically. The oysters and pectens have their shells well preserved; but hardly a trace of the original shell persists in the other mollusca, which are represented by very delicate and beautiful casts, showing all the markings and occasionally even traces of the original colour-banding. Ammonites were most abundant in the clays above the *Pinna*-bed, though not by any means restricted to this horizon. Our specimens are nearly all assignable to the species *Hoplites*

[1] G. W. Lamplugh, "On the Disturbance of Junction Beds from Differential Shrinkage and similar Local Causes during Consolidation." *Rep. British Assoc. for 1903*, (1904), pp. 666–7.

deshayesi, other forms being quite exceptional. The rarity of brachiopods is noteworthy, and may be associated with the absence of glauconite, as the conditions which produced this mineral in the Lower Cretaceous deposits seem to have been also the most suitable to brachiopodous life.

The basement bed of the Atherfield Clay reproduced almost exactly the phenomena observed at the base of the Sandgate Beds, differing only in the extreme thinness of the gritty layer, the absence of glauconite, and the smaller size of the particles. The last were chiefly crumbs of brown phosphate or bone, with a sprinkling of small black shining lydites and of pyrites. Tubular borings filled with this material went down for 3 to 4 inches into the underlying Weald Clay, though here no shells were found in the crypts. The floor was also cut up, as in the former case, by little grooves and channel-like burrows, evidently the work of organisms; so that small bits of silty clay, an inch or two in length, had been detached from it and embodied in the basement bed. With the exception of the crumbs of bone, however, no fossils were preserved in this basal layer, though abundant in the dark clay just above it.

The palæontology of the Atherfield Clay is discussed in Chapter IX., pp. 105-11.

Wealden Beds.

The attenuation of the marine Lower Cretaceous rocks in the Dover section, remarkable in itself, becomes of secondary consequence when compared with the reduction of the Wealden Series. Even excluding the Purbecks, the combined thickness of the Hastings Beds and Weald Clay in the country to the westward is estimated to reach over 2,000 feet[1]; and although the two divisions attain their maximum thickness in separate districts, and were perhaps in some degree contemporaneous and not superimposed to this depth at any one place, there can be little doubt that in some parts of the Weald they are represented by at least 1,200 feet of strata. But at Dover, while the two divisions are still recognisable, they are shrunken to a combined thickness of 85 feet only.

The three sections exhibited by the separate shafts differed in some minor points, particularly in respect to the very variable strata which we consider to be the equivalents of the Hastings Beds. In the following description we have combined the data into a single section:—

Section of the Wealden Series, Dover.

		Thickness. Feet.	Depth from surface. Feet.
	Gritty base of Atherfield Clay, resting on and interpenetrating— ... ... at	...	431
Weald Clay. (*cont. overleaf.*)	Greyish-blue clay with laminæ of pale silt, and films of ostracods, &c.	5	
	Dark blue and black clay laminated with silt and with layers of fresh-water shells (*Cyrena*, *Viviparus* and *Unio*), ostracods and fish-remains		

[1] W. Topley, "Geology of the Weald," *Mem. Geol. Surv.*, 1875, p. 322.

		Thickness. Feet.	Depth from surface. Feet.
Weald Clay, about 50 ft.	Laminated dark blue, brown, and greenish clay, dull-black elastic mud, and pale silt, with two bands of clay-ironstone 3–6 ins. thick, above and below, associated with fossiliferous pyritous layers. Ostracod- and-fish bands numerous, with *Viviparus*, *Cyrena*, &c.	8	
	Dark blue, grey and black clay and mud, with pale silty laminæ, and curiously mixed blue and grey bands mottled as if by the burrowings of small organisms and laced with tubular markings like *Sabella*-tubes, charged with comminuted shell-fragments. Shells rare, but many partings crowded with ostracods, bits of fish, &c., and some containing small rounded pellets of grey clay; at base, two clay-ironstone bands, 7 ins. and 3 ins. thick, with a shaly parting, full of fish-remains, &c.	21	
	Laminated blue, black, brown and grey clay or cyprid shale and silt, similar to the above, with *Cyrena*, *Viviparus*, &c., in some bands, and strongly marked layers of black and brown fragments of fish, with ostracods; toward the base one of these layers has a sprinkling of coarse grit grains (seen in No. 1 Pit only); at the bottom is a thin band of brown nodular claystone	11	
	Paler silty clay, intermingled blue and grey; tough greenish-blue mud; and brownish loam with plant-remains, lignite and pyritized wood; less shaly than the beds above, and forming a passage into the more sandy Hastings Beds below; no shells seen	5 ...	481
Hastings Beds, about 35 ft.	Pale grey silt interbedded with thin layers of tough blue-black pyritous mud or clay containing ostracods and fish-fragments ...	4	
	Pale greenish and yellowish-grey silt and clay as above, with seams of coarse sand passing into pebbly sand in No. 3 Pit ...	varying from 3–7	
	Mottled red and yellow ('catsbrain') gritty clay and silt	about 3	
	Brown and grey loamy clay and silt, with plant-remains, and streaks of black mud with ostracods as above	about 2	
	Pale greenish-grey and white sandy clay and silt, with streaks of lignite in places ...	6 to 8	
	Coarse white sand and silt, with pebbles of quartz and quartzite up to 3 ins. diameter in No. 2 Pit	1	
	Grey and brown clayey silt, with lignite, passing into—	1 to 2	
	Coarse white sand and silt with very variable pebbly bands or lenticles, and lignite, saurian bones, &c.; thickness varying from a few inches in No. 3 Pit to 9 ft. in No. 1 Pit	about 8	
	Resting on an eroded surface of Kimmeridge Clay, at		516

Weald Clay.—The change at the base of the Atherfield Clay from marine to fresh-water beds is so sharp and definite that we

were able to obtain excellent hand specimens of the junction. There can be little doubt that this junction marks an actual unconformity, accompanied by some erosion of the underlying beds; and although we could detect no difference of dip in the very gently inclined beds within the limited area of the pits, we were informed by the engineer-in-charge (Mr. A. Reid, F.G.S.) that he had recognised a slight increase of angle on reaching the shaly beds at the top of the Wealden Series. It has, therefore, to be considered how much denudation of the underlying series had taken place before the deposition of the Atherfield Clay. At Dover we found no trace of the estuarine fauna in the topmost beds of the Wealden, such as occurs in this position at Hythe[1], Redhill[2], and in the Isle of Wight[3], all the fossils obtained from the series being referable to fresh-water forms. This may imply some removal of the topmost part of the series, but there are many considerations which tell weightily against the idea that any great amount has been lost from the original thickness.

The basement bed of the Atherfield Clay has not the features of a shore deposit, but suggests the agency of currents in rather deep water; and it may be inferred that in this area the Wealden lake or estuary was submerged rather quickly beneath the sea. Some removal of the unconsolidated earlier deposits by marine currents during the change of conditions is probable, but is likely soon to have been arrested by the establishment of the still-water conditions necessary for the deposition of the Atherfield Clay. The junction is essentially similar to that in the Isle of Wight; the basement bed at Dover may be a reduced equivalent of the 'Perna Bed;' and the laminated shaly clays forming the upper part of the Wealden Series at Dover are analogous in all respects, except for their diminished thickness and the absence of the highest layers with estuarine fossils, to the Wealden Shales of the Isle of Wight. It has long been recognised that there is a great eastward thinning of the Weald Clay from its maximum of about 1,000 feet in Surrey to 300-400 feet at its most easterly outcrop near Hythe[1], and that the attenuation is still more rapid in a northward direction. Therefore, its shrinkage to 50 feet at Dover, 8 miles north-east of Hythe, though excessive, is not contrary to precedent, and does not entail the hypothesis of severe pre-Atherfield erosion, while the fact that the upper beds at Dover approximate more closely in lithological type to the upper part of the Weald Clay elsewhere than to any other portion of the formation appears to denote that the series is nearly complete so far as its higher members are concerned.

Its persistently shaly character at Dover—the presence of numerous strong partings formed by seams of fish-remains, crumbs of phosphate, ostracods, shells sometimes pyritized, and thin clay-ironstones—and the absence of unfossiliferous mottled red and yellow ('catsbrain') clays found at Pluckley (p. 61)

[1] "Geology of the Weald," *Mem. Geol. Surv.*, 1875, p. 98.
[2] "Summary of Progress for 1900," *Mem. Geol. Surv.*, 1901, p. 117.
[3] "Geology of the Isle of Wight," *Mem. Geol. Surv.*, 2nd ed., 1889, pp. 4, 15, 17.
[4] "Geology of the Weald," pp. 96–7.

and other places where the formation is thicker—all point to slow deposition in rather deep water at the bottom of a lake in an area sheltered from much influx of sediment.

The difference between these quiet-water deposits and the coarser sediments underlying them is precisely that which is everywhere found between the upper and lower divisions of the great Wealden Series, but is here accentuated by the reduction of both divisions to very narrow dimensions and by the stronger contrast in their distinguishing characters. The passage from one to the other was, however, gradual, so that the beds forming the lowest 5 feet of the Weald Clay of our section might be classed equally well with the Hastings Beds below them.

The fossils of the Weald Clay were, as usual, abundant in numbers but restricted in species. (For list and palæontological notes *see* Chapter IX., p. 111.)

Hastings Beds.—Below the comparatively regular and homogeneous strata assigned to the Weald Clay came a very variable series of pale silts, loam, mottled clay, and sharp coarse sands with pebbles, which differed in thickness, as well as in other particulars, in the three shafts, being apparently not much over 30 feet thick in the No. 1 Pit; about 35 feet in No. 2; and about 40 feet in No. 3; though exact measurements were impracticable owing to the absence of a well-marked upper limit. Incoherent quartz-sand with pebbles occurred principally at two horizons—one a few feet below the top of the series, and the other at the base; but whereas the latter band was 9 feet thick in the No. 1 Pit, it had almost thinned out in No. 3, being only 9 inches thick on one side of this shaft and 2 inches thick on the other; and the upper band was equally variable. We examined the base of the series in each of the three shafts and saw that in all of them the pebbly sands with masses of lignite rested directly upon an irregularly eroded surface of the blue-black Kimmeridge Clay. Of the Purbeck and Portland beds, which are present in force in the three inland borings, there was here not a trace.

It is clear that the series represents the Hastings Beds, but there is no evidence to show whether the Dover section contains a much attenuated equivalent of the whole division, which is estimated to have a thickness of quite 1,000 feet in Sussex, or whether it presents only some limited portion of the inland sequence. We do not know of any single section in the Wealden district which exhibits the combination of characters contained in the 35 feet of strata at Dover, although it is approached more nearly by some of the Isle of Wight sections in Brixton Bay. The structure and composition of the beds strongly suggest that they have been deposited in the bed of a powerful river, whose torrent was quenched at length by the spreading waters of the Wealden lake. If this be their origin, we must suppose that they were accumulated rapidly and cannot represent a prolonged period. The large size of some of the pebbles, the big rolled fragments of saurian-bones, and the masses of lignite and pyritized wood, indicate a forceful current which perhaps was long occupied in corrasion in this locality before it was sufficiently arrested to deposit a portion of its load. Certainly the huge pile of fine

sands, silts and clays which make up the mass of the Hastings Beds exposed in the country to the westward denotes the existence of a great land-drainage toward the central area.

Though not the prevalent opinion, to one of us it seems probable, for many reasons, that a large part of this drainage entered the Wealden basin from the north-east; and we think that the Dover section offers strong indication of the inflowing of a river from this quarter. With this in mind it becomes of particular interest to note the composition of the coarser sediments.

Both the silts and the sands were composed mainly of quartz, many of the coarser grains being conspicuously angular, and among them were a few small quartz-crystals, very slightly worn. The vast majority of the pebbles also were of milky-white vein-quartz, often quite subangular; they varied in their average size in the different bands or leuticles, sometimes ranging up to 2 or 3 inches in diameter, and sometimes smaller, with here and there a pebble much larger than the rest. The largest that came under our notice was an oval pebble of dark quartzite, measuring 4 inches by 2 inches; we also obtained a smaller one of liver-coloured quartzite or quartz, and another of dark hard grit or quartzite; but pebbles other than those of white vein-quartz were exceptional.

Considering the imperfectly worn condition of many of the pebbles and the wide range of rock-systems which must have been crossed by any river in Wealden times in flowing from an area of ancient quartz-veined rocks to this district ringed round by Mesozoic formations, it is remarkable that there should be such little variety in the pebbles. That the Mesozoic rocks should be seemingly unrepresented among them is indeed surprising, seeing that the lower gravelly bed rests directly upon an eroded surface of these rocks, which include much nodular and other hard material capable of yielding relics both to the pebble beds and to the sands. But the sharp differences in composition and structure between the sands and pebble beds of the Wealden Series and of the marine Upper Jurassic and Lower Cretaceous rocks present a problem which still awaits solution, and we must be content here merely to refer to it.

Kimmeridge Clay and Upper Corallian.

Our personal examination of the beds below the base of the Wealden at Dover was much less detailed than of the strata above this horizon. It was indeed at first intended to confine our work entirely to the latter, as the lower beds possess no outcrop in the Wealden district which it was our direct object to elucidate. Consequently, although afterwards it was decided to continue the investigation through the Jurassic rocks, our visits to the pits were made at less frequent intervals, and the examination of each stratum separately was not attempted. Our opportunities were, moreover, restricted practically to a single section, as the sinking of No. 1 Shaft was abandoned soon after it had entered the Kimmeridge Clay, and No. 3 Shaft (still unfinished) yielded us information at two horizons only in the Jurassic rocks—namely, at the top of the Kimmeridge Clay and at the iron-ore beds

100 feet lower in the section. The data which follow have therefore been collated almost entirely from our notes on No. 2 Shaft.

The break at the base of the Hastings Beds in the Dover section represents an unconformity accompanied by erosion of the pre-existing strata. The coarse fresh-water gravel above described was seen in all the shafts to rest directly upon an irregularly worn surface of dark clay containing many casts of marine shells of Kimmeridgian facies. The dip of the strata was, however, so low that no actual truncation of the bedding-planes was observable in the limited area proved by the shafts; a hard nodular band of calcareous claystone occurred all round the circumference of No. 3 Shaft at about 2 feet below the top of the clay, and appeared to be recognisable in the other shafts also, but at a slightly less depth in the clay. Hence there can have been only a very gentle tilting of the older strata before the newer beds were deposited; and this conclusion is borne out by the evidence of the inland borings, where, as we shall see, there is a practically unbroken and conformable sequence upward, from the Kimmeridge Clay and the marine sediments of Portlandian age, into estuarine and fresh-water deposits of Purbeck type which merge gradually into the great Wealden series.

It is an open question how much of the missing series was ever deposited at Dover, but there is at least a strong probability that marine sedimentation continued in this area into Portlandian times, though it is less likely that the Purbeck series was ever developed here. This view, of course, implies that the erosion at the base of the Wealden series at Dover has been considerable; and our palæontological work has brought out very clearly the extent to which the Kimmeridge Clay itself has been thereby reduced.

The thickness of the Kimmeridge Clay at Dover is slight when compared with its development in the Pluckley and Penshurst borings and at its outcrop throughout England; but the reduction is not entirely the result of erosion, as the Brabourne boring proves that the formation underwent also a rapid thinning eastward—a thinning accompanied by a change to a type of deposit previously unknown in this formation in England. At Dover this change is still more in evidence than at Brabourne, so that instead of the mass of bituminous shales and sandy clays with which we become familiar in following the monotonous outcrop of the Kimmeridge Clay from Dorset to Yorkshire, we find a thin development of variable glauconitic gritty material sprinkled with lydites, more akin in composition to the Sandgate Beds of the Lower Cretaceous than to any English Kimmeridgian sediments hitherto recognised. Clays are, indeed, interbedded and intermingled with this greensand, and it is also frequently indurated into hard concretionary calcareous rock-bands, often riddled with the perforations of boring organisms; but homogeneous beds of any kind rarely attain an individual thickness of more than a few inches, and never of more than a few feet. The deposit is, in fact, of the type which we have already described as indicative of a current-swept sea-bottom whereon sedimentation has been persistently slow and often temporarily arrested (pp. 10, 13).

Fortunately the fossils obtained from the series at Dover, though not very abundant or varied, have proved sufficient, when compared with those from the Brabourne and Penshurst borings, to enable us to estimate roughly the separate effect of the two factors. It will be shown in the second part of this memoir that the highest remaining beds of the present section belong to a horizon low down in the full Kimmeridgian succession. The equivalent thickness, in the western borings, of the beds present at Dover cannot be determined with precision, but we are able to estimate with fair confidence that the 44 feet of strata in this section have expanded to about 130 feet at Brabourne and to about 170 feet at Pluckley. The data for these conclusions are fully discussed in Chaps. X., pp. 148-53, and XI., pp. 188-91.

While the top of the Kimmeridge at Dover is thus rendered incomplete by erosion, the base of the series is difficult to fix because of its uninterruptedness and peculiarity of type. This difficulty, however, is one which is encountered in many parts of England. It has long been recognised that rocks of the true Corallian type are essentially 'episodal' in character, indicating only the local occurrence of peculiar conditions favouring the formation of coralline limestones and the local establishment of the special fauna which accompanied these conditions; while in other parts of the same sea-basin the deposition of clayey sediments went on uninterruptedly from Oxfordian to Kimmeridgian times, and preserved the relics of a fauna not easy to identify as contemporaneous with that of the coral-reefs. It is probable also that the coralline conditions were not absolutely simultaneous in the separate areas where they became established, so that the classification of their horizon cannot always be rigidly defined. In the Dover section, for example, the Corallian obtains its typical development in a series of characteristically fossiliferous limestones having a thickness of about 125 feet; but both above and below these limestones there are variable deposits of considerable thickness which are certainly of Corallian age. It is hard enough to select convenient boundaries for an irregular formation of this kind when it is adequately exposed at the surface; to do so on the limited information available in the present instance is still more difficult. Here again the palæontology of the deposits is our only guide, and although the fossils we obtained from this part of the succession left much to be desired, they are sufficient to justify the classification adopted in the following section (p. 22). A full discussion of the fossils, with the lists, will be found on pp. 112-20. The Upper Corallian subdivision in the section includes a group of strata of passage type, 96 feet thick, which intervenes between the undoubted Kimmeridge Clay and the undoubted Corallian limestone.

As might be anticipated, the Jurassic sequence at Dover between the base of the Hastings Beds and the top of the Lias will be found to match better with the strata of the same age on the French side of the Channel than with the equivalent outcrops in England which are geographically much farther removed. Both in lithological characters and in fossil contents the resemblance between the Dover sequence and that exposed in Bas Boulonnais, only some 20 miles distant, is unmistakable; and it

must, we think, be recognised as one of the most valuable scientific results of the Kent coal-explorations that they have yielded this link between the French and the English outcrops. Though it will not be practicable for us in this memoir to do more than indicate a few salient points in the correlation, we have little doubt that in some parts of the section a very close parallelism might be worked out.

The following was the succession of the Kimmeridgian and underlying beds, down to the top of the main Corallian limestones, in the No. 2 Shaft. The minor details, such as the individual thickness of the numerous calcareous hard-bands, have been generalised:—

Strata between Hastings Beds and Corallian Limestones, Dover.

		Thickness. Feet.	Depth from surface Feet.
	Hastings Beds, (*see* p. 16), to	...	516
Kimmeridgian, 44 ft.	Blue clay with casts of fossils, and a 6-inch nodular band of limestone	4	
	Green, greenish-blue, and dingy brown glauconitic sandy loam and clay, with numerous concretionary hard bands of limestone and claystone; the whole much dappled and streaked with coarse grit, lydites and glauconite, which often fill tubular borings ...	10	
	Clayey greensand and hard calcareous greensand-rock	6	
	Dark and pale blue and brownish clay with hard calcareous rock-bands; dappled and streaked with glauconite and polished grains of grit and lydite	15	
	Firm smooth pale-brown marly clay with thin layers of pisolitic rubble, shining 'millet-seed' ferruginous grains and hard concretionary rock	9	... 560
Upper Corallian, 96 ft.	Oolitic limestone...	8	
	Alternations of calcareous claystone, clayey oolitic limestone, muddy grit, bands of marly clay and layers of pisolitic rubble	18	
	Grey clay with a few shining 'ironshot' grains, alternating with brown gritty clay full of 'ironshot'	7	
	The 'millet-seed iron-ore':—small shining brown globules of iron-carbonate crowded in a slightly clayey or loamy matrix; with some calcareous claystone concretions ...	16	
	Hard concretionary rock-band with grains and rolled fragments of iron-ore, quartz-grit, lydites, &c.—3 ins.	8	
	Sandy clay, glauconitic in places, with streaks and bands of worn shell-fragments and pisolitic rubble		
	Laminated clayey sand-rock, showing current-bedding in places: much perforated by boring organisms	1	
	Calcareous claystone bands with thick partings of grey and blue sandy clay...	12	
	Dark blue and grey clay with silty layers (somewhat resembling the Weald Clay), and shelly layers, the latter particularly toward the base	26	
	on Corallian limestones at	...	656

In the above section it will be noticed that, as already stated, the predominant lithological character of the beds representing the Kimmeridge Clay was the abundance of glauconitic sandy clay or mud associated with irregular patches of coarse grit, including small polished pebbles up to ½ inch in diameter. In the lower division, classed as Upper Corallian, an oolitic character was well developed in many of the bands, occasionally in the form of layers of more or less oolitic limestone, but more frequently as a curious pisolitic rubble in which rolled pellets of clay, rounded fragments of shells, and large oolite-grains were loosely held in a somewhat clayey matrix, or locally agglomerated into hard concretionary masses which were often riddled by tubular borings filled in with the different material of an overlying stratum. The 'ironshot' bands were also a peculiar feature of this division, the small round shiny grains of iron-carbonate being, in the higher part, intermingled with others of calcareous or phosphatic composition, but lower down occurring profusely and almost unmixed in a thick belt, in the middle of the group, which thus becomes an iron-ore. In its structure and general characters this iron-rock is comparable with the well-known iron-ore of Westbury, in Wiltshire, also classed as Upper Corallian; and the associated pisolitic strata have likewise their analogues in the Wiltshire sections.

Corallian Limestones.

Below the heterogeneous Corallian strata above described there occurred at Dover a mass of limestones possessing the typical Corallian characteristics, with clayey and mixed calcareous beds below them of more ambiguous type. As the limestones formed a very distinct stratigraphical unit, we shall deal with them separately, and shall afterwards describe the underlying mixed beds in conjunction with the Oxfordian strata into which they merge.

The Corallian limestones were reached at a depth of 656 feet from the surface in No. 2 Shaft, and they continued downward, with some modification, to 782 feet, having thus a thickness of 126 feet. We visited the workings five times during the sinking of the pit through these beds in the autumn of 1900, which enabled us to obtain a fairly adequate collection from several horizons, though not from all. The following section is compiled from our notes: —

Section of the Corallian Limestones, Dover.

		Thickness. Feet.	Depth from surface. Feet.
	Shelly clays of the foregoing section, to	... ...	656
Corallian Limestones. (*cont. overleaf.*)	Creamy or greyish soft sandy limestone, with occasional layers of flaggy calcareous sandstone and of incoherent sandy shale; and with rubbly bands mainly composed of rolled bits of shell, oolite grains, &c., containing many gasteropods, and *Pecten*, *Lima*, *Ostrea*, &c.	about 20.	
	passing down into—		

		Thickness. Feet.	Depth from surface. Feet.
Corallian Limestones, 126 ft.	Coral Rag: irregular tabular masses of hard pale crystalline limestone, with hollows lined or filled with calcite crystals, usually in the interior of masses of coral or large gasteropods: around the hard masses, a softer rather sandy oolitic limestone full of fossils, and often with a strong bituminous odour	about 33 ...	709
	Creamy-grey soft calcareous stone of sandy texture, containing few corals, but many shells and *Cidaris* spines; with thin seams of very fossiliferous black shaly clay at the top and at the bottom	about 12.	
	Dark bluish muddy coral-limestone in hard tabular masses set in a softer calcareous matrix, with bluish-grey partings of calcareous silt: the coral masses frequently perforated by tubular borings and often converted in the interior into crystalline calcite: in limestone, the other fossils, few and poorly preserved, are mainly *Cidaris*-spines and the stem-ossicles of a large crinoid; but in the clayey bands, *Terebratulae*, &c., are abundant ...	about 61.	
	on Lower Corallian clays, &c., at... (*see* next page).	... ...	782

In this succession there was not only a lithological difference between the two main masses of limestone, but also a difference in their fauna. The upper 53 feet, of a pale creamy colour—almost white when dry—contained hardly any admixture of clay, the partings between the irregular masses of hard rock being chiefly composed of water-worn calcareous particles compacted into a soft rock, probably representing a 'coral sand' of the old reef, and material of this kind alone formed the uppermost 20 feet or so of the series. In these beds big handsome *Nerinea* and other univalves occurred in profusion and in a fine state of preservation, though difficult to extract; and there was also an abundance of large lamellibranchs of the genera *Pholadomya* and allies, *Lima*, &c. In the darker beds of the lower part of the series, where there was a considerable amount of clay both mixed with the limestone and in the form of dark shaly partings, the univalves and large bivalves were much rarer and generally in a poorer state of preservation; but there were many pectens, small oysters, and brachiopods, along with plentiful remains of large crinoids. Probably we have here the serial development of a local coral reef rising gradually above the range of the muddy sediments and reaching up into the zone of wave-action.

It is noteworthy that on the French side of the Channel limestones of the 'Rag' type are not everywhere present in the Corallian sequence, but they occur locally in the interior of Bas Boulonnais. Westward, on the English side, the Dover type of deposit persists at least as far inland as Brabourne, but may be replaced by deposits of different character in the interior of

the Wealden district if the Sub-Wealden boring near Battle has been rightly interpreted in the published accounts (*see* p. 81).

The palæontology of the limestones and their relations to the rest of the Corallian rocks are dealt with in the second part of this memoir, pp. 120-33.

Lower Corallian and Oxfordian.

There is an unbroken marine sequence at Dover downward from the base of the Corallian limestones to the sandy beds of the Kellaways rock; and as these intermediate strata have a pronounced stratigraphical unity, inasmuch as they show throughout a predominance of clayey deposits, we shall describe them together under the above heading. The grounds for the systematic classification which we have adopted in this part of the section will be stated fully when the palæontology of the beds is under discussion (*see* pp. 123-4).

The thickness of this clayey series is 176 feet., of which we assign, on the palæontological evidence, the upper 88 feet to the Corallian and the lower 88 feet to the Oxfordian, as shown in the section below. Several calcareous and gritty glauconitic rock-bands are included in the sequence, marking pauses of some length in the deposition of the clays and the local influence of currents. The attenuating effect of these conditions is brought out when the series is compared with its equivalent at Brabourne, where the same beds attain a thickness of over 230 feet.

The following section is compiled from our notes on No. 2 Shaft gleaned during seven visits while the sinking was in progress during the winter of 1900-1.

Strata between Corallian Limestones and Kellaways Rock, Dover.

		Thickness. Feet.	Depth from surface. Feet.
	Corallian clayey limestone above-described, to	... ...	782
Lower Corallian, 88 ft.	Dark blue clay with massive marly structure, in places indurated to marlstone, with bands of black rather sandy clay: containing large crushed plicatiloid ammonites, casts of *Trigonia* and other lamellibranchs, etc.	11	
	Dark splintery argillaceous limestone, non-oolitic, with clay partings: fossils scanty—crushed casts of large *Nerinea*-like gasteropods and a few lamellibranchs	about 7	
	Dark blue clay and marlstone, with massive marly structure, raising in irregular long slabs: fossils rather scanty and occurring in patches, mostly, except the oyster family, as casts; *Gryphaea dilatata*, *Exogyra*, etc.	about 20	
	Brownish clay and claystone, in places rather sandy and occasionally indurated into hard lenticular masses, with a little glauconite and with oolitic ferruginous grains abundant in dabs and streaks	about 10	
	Dark grey sandy clay	about 10	
	Brownish ironshot clay	about 2	
	Grey clay [only the lower part seen by us]	about 28 ...	870

		Thickness. Feet.	Depth from surface. Feet.
Oxford Clay, 88 ft.	Massive grey-blue marly clay and marlstone, with occasional streaks of silty clay and a few bands of semi-indurated claystone	about 52	
	Tough blackish silty pyritous clay associated with a band of hard green glauconitic sandy calcareous rock, containing pyritized ammonites and crushed black *Terebratulae*	about 1	
	Dull brown clay with massive marly structure, occasionally rather silty or sandy: recalling the Atherfield Clay in aspect and in the kind of life indicated by the sporadically distributed fossils: chiefly ammonites, small lamellibranchs, and a few gasteropods and crustacean fragments	about 18	
	Glauconitic calcareous stone band, like that above the brown clay	1	
	Pale grey rather sandy clay, with massive structure, full of casts of shells, chiefly lamellibranchs	about 15	
	Clayey rock with nodules, quartz grains and brown ferruginous oolitic grains; with casts of shells so abundant as almost to form a lumachelle	1	
	on rubbly ferruginous oolitic and sandy beds (Kellaways); at (*see* next page).	... ...	958

Our opportunities for collecting from these strata generally, and especially from the thick masses of clay in the middle part of the series, were inadequate, as the sinking was carried down rapidly during the short dark days of mid-winter (1900-1), and in the intervals between our fortnightly visits much of the excavated material had been covered up or had been swept away by the sea. Therefore the fossil-lists given in a later chapter (pp. 130-6) are only an imperfect representation of the fauna. Nevertheless they suffice to show that the top beds belong to the zone of *Cardioceras cordatum*, which is now counted to be Lower Corallian, and that the sequence of the fossils in the underlying Oxford Clay agrees with the zones recognisable in the same formation at its outcrop.

The thick bed of brown clay in the lower portion of the series was interesting from its similarity to the Atherfield Clay—a similarity which was closely reflected in the genera and in the mode of preservation of its fossils. The conditions of the sea-bottom in the locality at these two widely-separated periods must have been almost identical.

Basement Beds of Middle Oolites and upper part of Lower Oolites.

The strata between the Oxford Clay and the main limestones of the Great Oolite Series consist of a variable group of intermingled sandy and clayey deposits, generally more or less calcareous and including many subordinate bands of impure limestone, which appear to represent a continuous sequence of marine deposits, but

which have not as yet yielded sufficient palæontological evidence to enable us to trace out their subdivisions with confidence. It is to be remembered, however, that both in England and in Northern France the upper portion of the Lower Oolites is characterised at the outcrop by great instability of lithological composition, especially in the beds below the Cornbrash, and by many peculiar local modifications of fauna, so that the conditions at Dover are not anomalous. The Dover sequence has indeed many points of resemblance with the equivalent series of Western England on the one hand and of Bas Boulonnais on the other, though it cannot be correlated in exact detail with any particular section of either outcrop.

The Kellaways Rock at the base of the Oxford Clay can be identified with certainty, being represented by a mass of loamy calcareous sand and sand-rock, somewhat ferruginous and in places indurated into concretionary limestone. Lithologically, therefore, it is of the normal Kellaways type, and the correlation is established by the fossils which we obtained from it (*see* p. 136).

The recognition of the Cornbrash in the section is not so certain, as the fossil-evidence yielded by the belt of sandy calcareous clay which we have assigned to this subdivision was scanty, but our correlation has been strengthened recently by evidence obtained from a new sinking at Tilmanstone (*see* p. 138).

The case for the identification of the Forest Marble Series stands on a more speculative footing than that for the Cornbrash. The fossils were few, imperfect, and without value for the correlation, so that we have to depend upon the composition and stratigraphical relations of the rocks. The topmost bed of the group, according to our classification, is a band of pale oolitic limestone, without any special characters and resembling some of the Great Oolite limestones that occur a little lower in the section. It was the highest limestone of this type in the Lower Oolites, and the first clean limestone found in the sinking below the base of the Corallian limestones. The dark grey marl below it possessed no distinctive features, but the underlying claystones, which we have placed at the bottom of the group, showed lithological peculiarities which can be almost exactly matched in the Forest Marble Series of Oxfordshire. The pale claystone mottled with branching streaks of green clay is very distinctive, while the darker claystones below have a characteristic thin-bedded flaggy aspect that denotes variable and recurrent conditions of accumulation.

The succession and thickness of the beds here dealt with are summarised in the following section:—

Strata between Oxford Clay and Great Oolite Limestones, Dover.

		Thickness. Feet.	Depth from surface. Feet.
	Clayey rock-band at base of Oxford Clay, to (*see* last page).	...	958
Kellaways Rock. (*cont. overleaf.*)	Hard yellowish-brown calcareous claystone with dark brown ferruginous or phosphatic grains, passing down into similar rock intermingled with blue-hearted concretionary clayey limestone: containing *Pseudomonotis* and *Gryphaea*, but few other fossils ...	5 to 6	

		Thickness. Feet.	Depth from surface. Feet.
Kellaways Rock, 35 ft.	Streaky dull grey and greenish loamy sand, dappled with dark clay, and thin tubular borings (?); with incipient concretionary structure, and irregular nodular hard bands in the lower portion. *Belemnites* and *Gryphaea* the most abundant fossils ...	24	
	Band of hard concretionary limestone in a matrix like the above. *Pteria*, *Trigonia* (clavellate), &c.	2	
	Dull grey and greenish loamy sand, partly indurated, as above. No fossils seen ...	3	... 993
? Cornbrash, 13 ft.	Bluish-grey streaky sandy clay of marly structure; with masses of indurated calcareous rock, small soft brown nodules, and markings like borings. *Pholadomya* and *Pleuromya* (crushed casts), *Pseudomonotis echinatus*, *Modiola*, *Astarte*, *Pecten*, &c. ...	13	... 1006
? Forest Marble, 18 ft.	Pale yellowish oolitic limestone, with obscure fragments of shells including *Pteria* ...	4	
	Dark greenish-grey clay-marl, with shell-crumbs and patches of oolite-grains: *Pleuromya*	3	
	Compact pale greenish calcareous claystone, interpenetrated by green clay in ramifying finger-like processes: few fossils except a seam of broken *Ostrea*? and spines of echinoderms	3	
	Compact bluish-grey calcareous claystone, with darker somewhat oolitic bands, containing fish scales, large and small fragments of lignite, and small pale brown phosphatic nodules. *Modiola*, *Astarte* and other indet. fossils	8	
	on dark blue oolitic limestone (*see* p. 29), at	...	1024

Great Oolite Limestones and underlying Sands.

Of the remainder of the Oolites at Dover it is certain that the greater portion, consisting in the upper part of limestones and in the lower part of calcareous grit and sand, belongs to the Great Oolite Series, as this is proved by the presence of characteristic fossils. But at the base there are some apparently unfossiliferous grits and sands in which the Inferior Oolite may possibly be represented. Our information respecting these lower beds is, however, scanty, being derived solely from the examination of the cores of a boring, 10 inches in diameter, which was sunk from the bottom of the shaft. As previously mentioned, the shaft itself was carried down during our investigation to a depth of about 1,083 feet, which was 37 feet above the base of the Oolite Series, and down to this level we had the opportunity to study and collect from the full supply of material on the tip-heaps. The results obtained below this level are therefore necessarily meagre and unsatisfactory as compared with those from the strata above it. We must remember, however, that in Bas Boulonnais there is an unfossiliferous sandy series below the Bathonian limestones and marls, which appears to correspond very closely to the lowest portion of the Oolitic division at Dover, so that even if our facilities had been greater it is doubtful whether any palæontological evidence for the age of the lowest beds would have been

forthcoming. No sands were found at this horizon in the Brabourne boring, and from the general tenour of the evidence, to be subsequently discussed, it is evident that an important change of conditions ensued after the deposition of the Upper Lias, which was accompanied by much erosion, and is therefore quite likely at any particular locality to be marked by a gap in the sequence.

The section down to the base of the Oolites at Dover may be summarised as follows:—

Great Oolite Limestones and underlying Sandy Beds to top of Lias, Dover.

		Thickness. Feet.	Depth from surface. Feet.
	Forest Marble Series?, *see* above, to ...	...	1,024
Great Oolite, 69 ft.	Dark blue compact oolitic limestone of fine texture	4	
	Pale yellowish oolitic limestone of fine texture, with occasional coarser streaks and patches; curiously mottled and intermingled with the dark blue rock toward the top: containing only comminuted shell-fragments	12	
	Grey and mottled sandy limestone, occasionally oolitic, with many crushed fossils: *Terebratula bathonica, Rhynchonella; Pecten, Ostrea* and other bivalves; and traces of corals	5	
	Fine-grained sandy limestone with oolite grains and specks of lignite, banded in sharply contrasting tints of dark-grey and yellowish-grey; no fossils seen	11	
	Grey oolitic limestone with crystalline lustre-mottling: fragments of *Terebratula* and *Ostrea*	3	
	Grey or yellowish sandy limestone with quartz-grains coated with calcareous matter; speckled with lignite and containing a thin parting with many crushed shells—brachiopods, oysters, &c.	1	
	Dark grey fine even-grained calcareous sand or sandrock	4	
	Dark grey and bluish-grey calcareous sand and sandstone, with calcite-coated grains and with occasional bands of sandy limestone, containing fragments of *Ostreae* and *Serpulae*	9	
	Sandy limestone, variable and slightly oolitic in places; containing numerous badly preserved brachiopods and lamellibranchs, including *Ostrea sowerbyi, Placunopsis socialis*, &c. (*see* list, p. 140)	4	
	Grey sandy limestone; and grey sand with hard globular calcareous concretions up to 1 to 2 ft. in diameter, sometimes containing nests of fossils — brachiopods, oysters, serpulae, &c.	3	
	Alternations of consolidated grey sand and bands of compact sandy limestone or calcareous grit sparingly oolitic in places, with a bed containing *Ostrea sowerbyi, Pholadomya deltoidea*, &c. in the upper part	3 ... 1,083 (Below this depth, seen in 10-in. boring only.) 10 ... 1,093	

		Thickness. Feet.	Depth from surface. Feet.
? Inferior Oolite, 27 ft.	Grey calcareous grit and sand like the above, with a 5-ft. band of dark grey sandy clay and indurated silt, slightly speckled with small bits of lignite in places; indeterminable shell-fragments only...	16	
	Quartzose sand and fine grit, with indurated calcareous band toward the base	11	
	on Lias Clays (*see* p. 31), at		1,120

The top bed of the above section was a peculiarly dense fine-grained oolite, of a dull blue-black colour like the stain of weak ink. This rested on pale limestones of similar texture, and there was a curious mottling and interpenetration of the two strongly contrasting colours at the junction of the beds. In the remainder of the series most of the limestones had a gritty texture due to a considerable admixture of fine sand, which increased in proportion until, at about 36 feet below the top of the section, it became the preponderant constituent. The rock-bands below this level were essentially calcareous grits embedded in a matrix of semi-indurated calcareous sand, in which at one horizon there were very hard ball-like fossiliferous 'doggers.' Most of the sandy limestones were besprinkled with fragments of sooty lignite, which appears also to be a conspicuous feature in the beds at about the same horizon in Bas Boulonnais.

Fossils were very scanty, fragmentary and ill-preserved in most of these beds, and were difficult to extract from the few seams in which they were more abundant. Sufficient data were obtained, however, as the list will show, to leave no doubt as to the Bathonian age of the limestone series[1], the species including the characteristic *Terebatula bathonica*, *Ostrea sowerbyi*, *Placunopsis socialis*, &c. The correlation is also supplemented by some additional Bathonian forms collected from the equivalent strata of the Brabourne boring (*see* p. 169).

So far as we could judge from the imperfect evidence afforded by the boring cores, the sands at the bottom of the Dover Oolites were mostly coarse-grained, composed almost wholly of particles of quartz, with a little disseminated pyrites; they were only slightly consolidated, and contained a few small quartz-pebbles up to ¼ inch in diameter. The character of the junction of this deposit with the Lias could not be determined from the material available.

Lias.

With the prospect that another shaft will eventually be carried down through the Lias at Dover under conditions more favourable for the investigation of the strata than was the case with the first shaft, it would be premature for us to discuss this part of our subject at much length on the imperfect knowledge which we now possess. The boring-cores show that some portions of the series are richly fossiliferous, and we may therefore expect that the

[1] In the section published in the "Final Report of the Royal Commission on Coal Supplies," pt. ix. (1905), p. 47, these beds down to the Lias are included in the Kellaways Rock.

material which would be available during the sinking of a shaft under normal conditions would furnish decisive evidence on some points of consequence which are as yet uncertain. In the Brabourne boring we obtained satisfactory proof that the Upper, Middle and Lower divisions of the Lias were all represented (*see* pp. 170-8), and although the series at Dover is very much thinner than at Brabourne, we shall be able to show, by palæontological evidence, that the same is the case at Dover also (*see* pp. 141-3). The conclusion is of much interest, since it supplies a very striking example of the singular persistence of extreme attenuation in the Mesozoic sediments of this area. The absence, so far as is known, of Liassic strata in Bas Boulonnais adds further consequence to this part of the Dover section, inasmuch as it supplies us with the most easterly occurrence of the formation in the Franco-British basin. It is sincerely to be hoped, therefore, that the formation will be very carefully studied on every opportunity which may be afforded during the future development of the Kentish coal-explorations.

The following section is compiled from the record of the boring through the Lias, for which we are indebted to the engineer in charge. The descriptions in Roman type are derived from our personal examination of the cores; those in italics are given on the authority of the borers' record.

Section of the Lias, Dover.

From the record of a 10-inch Boring.

		Thickness. Ft.	In.	Depth from surface. Ft.
	Oolitic sands (*see* last section) to ...	...		... 1,120
Upper Lias, 6 ft.	Grey clay with massive marly structure, containing many fossils, chiefly lamellibranchs, ammonites of the genus *Dactylioceras*, and obscure plant-remains ...	6	0	... 1,126
	Calcareous sandstone ...	2	10	
	Hard grey limestone ... (No fossils seen in these beds.)	2	0	
	Dark grey sandy clay with a thin band of limestone... (No fossils seen in these beds.)	1	4	
	Hard grey limestone ... (No fossils seen in these beds.)	2	2	
? Middle Lias, 16 ft.	Hard dark grey sandy calcareous clay or marlstone, with specks of lignite and fossils, including *Belemnites* and *Rhynchonella*; comparable to part of the Middle Lias at Brabourne	1	6	
	Hard grey limestone	1	0	
	Dark grey sandy calcareous clay, as above, full of small fragments of shells and broken belemnites	0	9	
	Dark grey calcareous sandstone... ... ... (No fossils seen.)	4	6	... 1,142
	Dark grey marl ... ... (No fossils seen.)	3	3	
	Dark grey clay ... ... (No fossils seen.)	2	8	
	Marl ... ... (No fossils seen.)	6	0	
Lower Lias, 16 ft	Grey smooth clay with massive marly structure, containing many fossils, chiefly small crushed lamellibranchs (*see* list, p. 142) with white shells: exactly resembling part of the Lower Lias at Brabourne	4	0	
	on Coal Measures shales, at ...	...		... 1,158

The fossil-lists and palæontological descriptions are given in Chap. IX., pp. 141-3.

With respect to the classification adopted in the section, it will be seen that the Upper Lias age of the topmost clay is established by the palæontological evidence. It is certain that there is an unconformity at the base of the Oolites, and that the Lias has been planed down to some extent by erosion prior to the deposition of the overlying sands. Indeed, the character of these sands implies the scouring agency of agitated waters, either on a coast or on a shallow sea-floor, and this initial probability of unconformity is supported by the evidence of the fossils and their comparison with those obtained from the Upper Lias at Brabourne (p. 198). Making every allowance for erosion of the uppermost beds, however, the attenuation of the rest of the Lias in the Kentish sections is astonishing; and from the evidence of the Brabourne section we know that the top beds there, that are absent at Dover, shared equally in this general attenuation from their usual English development.

The recognition of the Middle Lias and the delimitation of its boundaries at Dover rest on slender evidence. Most of the bands of rock which we have included in this division yielded us no fossils, and the specimens obtained from the one prolific horizon lack determinative value, though the presence among them of numerous *Rhynchonellae* is significant.

Seeing, however, that we have proof of the Lower Lias age of the underlying beds, and that the deposits agree in lithological type with a portion of the much thicker Middle Lias series occurring at Brabourne, we think that the correlation is substantially justified. The beds which we have included in the division nearly all showed a very perceptible admixture of loamy sand, whereas the beds above and below were almost devoid of this constituent. It is noteworthy that the same distinction is commonly found, to a varying degree, in the Middle Lias of most parts of Britain; and its persistence in Kent, where the whole formation is reduced to comparatively insignificant dimensions, is remarkable.

The beds which are classed as Lower Lias in the Dover section consisted almost entirely of smooth homogeneous blue-grey clays or marls, in which we found fossils only in the lowermost 4 feet, where they were abundant. Our collection from them did not include any cephalopod, but Mr. J. Gerrard, His Majesty's Inspector of Mines (to whom our thanks are due for much assistance during our investigations), was more fortunate, and has submitted to us a specimen of *Liparoceras maculatum* (Y. and B.) from this horizon, which places beyond question the presence of the Lower Lias in the section. Further evidence was provided by the Brabourne boring, where the much thicker clays of exactly similar type and in the same relative position in the sequence yielded several other Lower Lias forms (p. 173-4).

Owing to the imperfect condition of the cores at the time of our examination (in 1903) we were unable to study the nature of the junction of the Lias with the underlying Coal Measures, which is another matter deserving close attention whenever this horizon is again reached. It is evident, however, that the sandy ferruginous basement beds which were conspicuous in the Brabourne boring (*see* p. 50) are absent at Dover.

CHAPTER III.

THE BRABOURNE SECTION.

General Notes. — The site of the Brabourne boring lies 13¾ miles W10°N. from the Dover Shafts, and 2½ miles N20°E. from Smeeth Station on the South Eastern Railway, at a height of 215 feet above Ordnance Datum[1], close to a little stream which runs past the farmsteads of West Brabourne. The boring was begun in the year 1897 and finished in the autumn of 1898, having then reached a depth of slightly over 2,000 feet. The diameter of the cores diminished from 11 inches in the upper part to 2 inches at the bottom. We examined and collected from the material at frequent intervals during the progress of the work; and when the apparatus was dismantled in the spring of 1899, the whole of the remaining cores were placed at our disposal, and were systematically broken up and searched for fossils[2]. The descriptions which follow are summarised from our notes made at the time, with supplementary information derived from the later study of the full collection now in our keeping at the Survey Office. So far as we are aware, the only first-hand account of this important boring hitherto published is a brief statement, giving only the thickness of the several formations believed to be present, without further description, issued by the late R. Etheridge in 1899[3]. This account has since been repeatedly quoted and discussed by other writers, but without material addition.

The boring started upon the outcrop of the Gault at about 65 feet above the base of this formation, and therefore at a stratigraphical horizon about 180 feet lower than that of the Dover shafts. It reached the Palæozoic floor at a depth of approximately 1,925 feet, so that the Mesozoic rocks that were penetrated were quite 1,000 feet thicker than the corresponding column of these rocks at Dover, or nearly double. A portion of this great increase is accounted for by the presence at Brabourne of Purbeck, Portland, and Triassic strata which are missing at Dover, and of parts of other formations which are incomplete there; but most of the increase is due, as we shall presently see, to the persistent thickening of formation after formation when compared with its Dover equivalent.

Though unprofitable in its commercial aspect, we regard this boring as being, from the scientific standpoint, the most important of the Kentish explorations. The two borings farther westward which we were allowed to investigate both lay within the region of such increased sedimentation that they failed even to reach to the base of the Upper Jurassic sequence; those to the

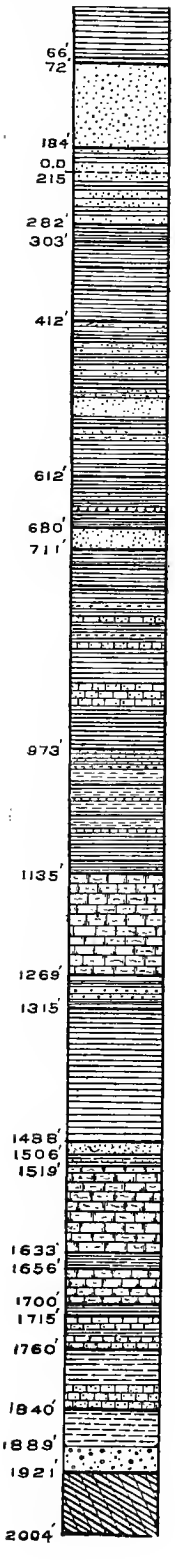
[1] The altitude has been erroneously given as 322 feet in some of the previous literature.

[2] This duty was skilfully carried out by Mr. John Rhodes, who was at that time the Survey fossil-collector.

[3] *Rep. British Assoc.* for 1899 (pub. 1900), p. 733; and in a report to the Kent Collieries Corporation, quoted in *Final Rep. Roy Com. Coal Supplies*, 1905, pt. x., p. 30. *See* also "The Water Supply of Kent," *Mem. Geol. Surv.*, 1908, p. 222.

FIG. 3.—BRABOURNE: SUMMARISED SECTION OF THE BORING.

Scale: 1 inch = 250 feet (same as Fig. 2).



	Thickness. Feet.	
Gault (incomplete at top), with soil, etc.	66	Upper Cretaceous.
? Mammillatus band	6½	Lower Cretaceous.
Folkestone Beds (sands)	111½	
Sandgate Beds (? with Hythe Beds); details, at p. 36 ...	98	
Atherfield Clay; details, at p. 36	21½	
Weald Clay; „ p. 37	109	
Hastings Beds; p. 38	200	
Purbeck Beds; „ p. 38	78	Upper Oolite.
Portland Beds; „ p. 41	31	
Kimmeridgian Beds; „ p. 42	262	
Upper Corallian Beds, with iron ore; details, at pp. 42–3. ...	162	Middle Oolite.
Corallian limestones; details, at p. 46	134	
Lower Corallian Beds; „ p. 46	46	
Oxford Clay; „ p. 46	173	
Kellaways Rock (? with Cornbrash); details, at p. 46 ...	18	
Forest Marble Series; details, at p. 48	13	Lower Oolite.
Great Oolite limestones; „ p. 48	114	
? Fuller's Earth Series; „ p. 48	23	
? Inferior Oolite limestone; details, at p. 48 ...	44	
Upper Lias; details, at p. 50	15	Lias.
Middle Lias; „ p. 50	45	
Lower Lias; „ p. 50	80	
Triassic Marl; „ p. 54	49	Trias.
Triassic Conglomerate; details, at p. 54	32	
Palæozoic slaty mudstone · p. 54	83 .	Devon-

northward, so far as the meagre data hitherto published enable us to judge, fall within the region of unconformable overlapping, where the Mesozoic succession is imperfect; but the Brabourne section reveals to us the conditions of the intermediate belt, adjacent on the one hand to the rising northerly land, and on the other to the deepening southerly basin, and itself constantly affected by these reciprocal movements, yet always to a comparatively slight degree.

The sequence, therefore, embraces more than is likely to be attained again in a single boring, and comes second only to the Dover record in its condensed representation of a vast range of Mesozoic time, while it surpasses Dover in possessing strata belonging to the earliest period of that time—the Triassic—which has not been identified with certainty in any other boring in the south-east of England. We may be allowed here to reiterate that the Dover and Brabourne sections are unparalleled in Britain—or, so far as our knowledge goes, in any other part of the world—in the geological range and continuity of formations proved by them to exist in actual superposition in a single small area.

The complete Brabourne section is shown on a small scale in Fig. 3. Fuller details of the different formations will be given in the same order and, as far as possible, under the same classification as in the preceding account of Dover.

Gault and Lower Greensand.

The upper part of the boring, down to a depth of 238 feet, was done by means of chisel-tools, so that no core was drawn and the only material available for examination was in the form of smashed *débris*, of little use for critical study. We have therefore had to depend almost entirely on the engineer's records for our information respecting this portion. Cores were made for the next 44 feet, or to a depth of 282 feet; after which the chisels were again used for the space of some 20 feet, which brought the boring into the top of the Weald Clay at a little over 300 feet from the surface. From this depth downward, continuous cores were available, except for slight interruptions where the beds were not sufficiently coherent to bear extraction in this form.

The following section of the strata above the Weald Clay is compiled from the journal of the boring, supplemented by the additional information gleaned from the 44 feet of cores and from the heap of chiselled *débris*. Where the description is wholly that of the engineer, it is printed in italics. As before, the figures are given in terms of the nearest foot, with inches usually omitted.

Strata above the Weald Clay at Brabourne.

		Thickness. Feet.	Depth from surface. Feet.
	Soil and flinty valley-gravel... ...	4	
Gault, 62 ft.	*Dark blue clay*	57	
	Sandy clay with green veins... ...	3	
	Black sand [? phosphatic and pyritous base of Gault, broken up by the chisels]...	2	... 66

		Thick-ness. Feet.	Depth from surface. Feet.
? Mammillatus Bed.	*Dark grey sand with pieces of black sandstone*	6½	
Folkestone Beds, (together) 118 ft.	*Grey sand* [apparently all incoherent, and without rock-bands]	111½ ...	184
Sandgate Beds (? with Hythe Beds), 98 ft.	*Dark green loamy clay*	20	
	Dark green loamy sand	11	
	Brown sand	4	
	Loamy sand	4½	
	Loamy clay	3½	
	Grey loamy sand	10	
	Greenish-grey fine-grained silt, loam and marl with occasional semi-indurated sandy bands and layers of pyritous clay: also some hard claystone nodules, soft brown phosphatic nodules, rod-like concretions or markings, and some veins of gypsum: slickensided surfaces plentiful throughout: no 'Kentish Rag' seen, and the whole series akin to the Sandgate Beds of Dover. Fossils, chiefly casts, in a greyish-green loam near the top, include an ammonite-fragment, *Ostrea*, *Exogyra*, *Pecten* (*Neithia*), &c. (*see* p. 144) ...	45 ...	282
Atherfield Clay, 21½ ft.	*Hard brown clay*, with marly structure, exactly resembling the Atherfield Clay of Dover... ...	18	
	Hard blue clay	3½	
	Top of Wealden Series, at ... (*see* next page).	... ...	303½

Respecting the Gault of the above section we have no further particulars. The "pieces of black sandstone" in the "dark grey sand" at its base were probably broken nodules of phosphatic grit like those of the Mammillatus band occurring in a similar position in the cliff section at Copt Point, but we saw no specimen of this material. If this conjecture be correct, the expansion of the Mammillatus Bed from its extreme attenuation at Dover is noteworthy.

The underlying thick sands have their outcrop ½ mile to the southward of the boring, and they may be followed thence eastward continuously, though with changing lithological characters, into the cliff section of the Folkestone Beds at Folkestone. The expansion of these sands from 2 or 3 feet at Dover to 111 feet at Brabourne is an exaggerated instance of the general relationship of the two sections.

The strata underlying these incoherent sands were clearly of the Sandgate type—variable dark green loams, intermingled with pyritous clay—and beds of this character prevailed downward to the top of the Atherfield Clay, the lower 44 feet being represented in the cores which we examined. They showed no perceptible dip in the bedding, excepting at the depth of about 250 feet, where the strata were locally crumpled and lying steeply. The absence of calcareous stone-bands ('Kentish Rag') and other peculiarities distinguishing the Hythe Beds

was remarkable, seeing that the outcrop of this division occurs only 2 miles south of the boring and displays its usual characteristics. Either the Hythe Beds in this short interval have thinned out or they have been replaced by deposits of the Sandgate facies. The conditions in this part of the section are thus analogous to those at Dover (*ante* p. 11-12), and the thickness of the loamy and clayey greensand at Brabourne (98 feet) is only 20 feet greater than at Dover. Unfortunately the cores did not continue to the junction of these beds with the Atherfield Clay, so that there was no opportunity to discover whether it possessed the sharp character which it had at Dover.

The Atherfield Clay was seen only in chisel-cut fragments, which nevertheless sufficed to show that its lithological composition remained the same as at Dover, both the chocolate brown and the blue varieties being present. The division is exceptional, however, in being much the thinner (only a little over 20 feet) at Brabourne. But its exact thickness was rendered somewhat uncertain by the absence of cores[1].

Wealden and Purbeck Series.

In comparison with the Dover section we find at Brabourne a relatively full development of the great Wealden fresh-water series, though the thickness is still astonishingly small when compared with that of the equivalent deposits in the borings farther westward and in the outcrops a few miles distant to the southward. In detail the beds differ widely from those of Dover, though a general similarity of sequence can be recognised until we reach the lowest horizon represented at Dover. Below this horizon we find some additional masses of strata with which we make our first acquaintance at Brabourne, and these are of peculiar interest inasmuch as they reveal to us the history of the beginning of the Wealden episode, hitherto unknown in this part of Kent. The boring cores through this part of the section ranged between eight inches and six inches in diameter, affording scanty material for investigation as compared with the Dover shafts, yet sufficient to indicate clearly the lithological characters of the strata and to give some idea of the fauna. From our examination of these cores, the following section has been compiled :—

Section of Wealden and Purbeck at Brabourne.

		Thickness. Feet.	Depth from surface. Feet.
	Atherfield Clay (*see* p. 36), to ...	...	... 303½
Weald Clay, 109 ft.	Alternations of tough blue-black clay and streaky grey clay and silt; much slickensided in places: few or no fossils seen, except numerous fish-scales	12	
	Grey laminated shaly clay, with seams crowded with *Cyrena*, *Unio*, and cyprids	about 5	
	Alternations of dark clays and paler silty clays, as before, with a few bands of grey calcareous claystone from 2 to 4 inches thick: fossils rare, except fish-scales	92	... 412

[1] Its base may be a little above or below the depth given in our section : we have adopted the figures already published by R. Etheridge (*op. cit.*), as it is needlessly confusing to vary such details without strong reason.

		Thickness. Feet.	Depth from surface. Feet.
Hastings Beds, 200 ft.	Grey sandy silt alternating with tough mud and compact marly clay, in part dark and streaky	19	
	Mottled red and green hard clay or marl and pale green marl with semi-nodular structure, with two or three bands of calcareous ironstone, up to 4 ins. thick	26	
	Darker muddy clays with stone-bands, and beds of greenish marl: fish-remains and cyprids abundant in a gritty phosphatic layer, and fresh-water shells (*Cyrena*, *Viviparus*) in other layers	18	
	Banded light and dark grey silts with a nodular band; and brown silts with lignite and plant-remains, including *Onychiopsis mantelli* toward the base ...	35	
	Pale rather coarse sand, with green grains and masses of lignite near the top (no cores obtained for the bottom part) ...	22	
	Muddy silts, brown, dirty grey, and paler below, with fragments of plants ...	34	
	Band of hard calcareous grit with crystalline structure	1	
	Pale silts	23	
	Mottled red and yellow clay with marly structure	22	... 612
	Brownish-grey muddy silts		
? Purbeck	Green and yellow mottled clay with marly structure and slickensides; passing down into greenish silty sand containing fragments of fresh-water (?) shells ...	12	... 624
Purbeck Beds, 56 ft. + ? 12 ft.	Peculiar earthy breccia of soft yellowish claystone fragments in a matrix of green sandy loam with bits of lignite and cast of a shell, like *Unio*	3	
	Variable series, including bands of green silty breccia as above, shaly breccia of pale grey and green marl, hard green shaly clay, all much slickensided, with *Cyrena* and fragments of other shells; and hard flaggy beds of smooth compact grey calcareous claystone with cyprids and a few shells; pale bright-green marl at base	13	
	Mottled green and yellow marly clay, with a few fossils as above, and fragments of plants	10	
	Banded pale and dark grey indurated clay or marl, smooth, compact and flaggy, with a brecciated band 4 ft. from top, and a layer of phosphatic nodules 5 ft. above base: fossils rare, except cyprids, fish-remains, and bits of wood occasionally	15	
	Pale smooth calcareous claystone-flags with compact splintery fracture; including a dark gritty earthy layer (? 'dirt-bed') at 3 ft. from top, speckled with brown (? bone) and white (? shell) particles: mostly unfossiliferous, but with insect-remains near top, and cyprids and fish-scales in occasional layers	about 8	
	Green marly band, followed by thinly laminated black shale and pale brown claystone-bands, irregularly bedded ...	about 7	
	Junction with Portlandian, not clearly seen, at (*see* p. 41).		... 680

The fossils in our collection from the above series, which have been identified, are few in number, for not only are most of the specimens imperfectly preserved, but there is the further difficulty that the fresh-water molluscan fauna of the British Wealden Series has never yet been thoroughly studied, so that the basis for satisfactory specific determination is frequently wanting. The lists given in Chap. X., pp. 144-5, have little value for comparative purposes, but afford serviceable indications of the conditions under which the strata were deposited.

While the main points of the above succession were clear, there were no strongly marked limits to the subdivisions, and the boundaries which we have adopted are necessarily more or less conventional. As at Dover, the Wealden beds proper were divisible into a dark clayey series above, representing the Weald Clay, and a mixed series of clays (in part brightly coloured), silts and sands below, representing the Hastings Beds.

The Weald Clay was over twice the thickness of its equivalent at Dover, and differed from it in the much feebler development of the laminated shaly type of deposit and in the comparative rarity of the highly fossiliferous layers associated with this type.

The Hastings Beds, with a thickness of 200 feet, were nearly six times thicker than at Dover. Of this great increase, about 80 feet might be explained by the incoming of beds below the base of the Dover series, while the remainder was evidently due to the expansion of every individual portion of the Brabourne section above the sands. If the two sections be compared, it will be seen that there is a remarkable agreement in the lithological characters of the succession—the grey silts, the brightly coloured clays, and the brown silts with plant-remains, each occurring in the same relative position, but swelling out from a band of a few feet only in the one section to a much thicker mass in the other. This systematic habit of expansion renders it the more probable that the representatives of a very considerable portion of the Hastings Beds are compressed within the 35 feet of strata at Dover.

The 22 ft. bed of pale sand at Brabourne was not sufficiently coherent in some parts to make a continuous core; but, so far as we could ascertain, it was free from the pebbly bands and coarse grit contained in the equivalent bed at Dover. In its increased thickness, as well as in its finer texture, it indicates, like the rest of the series, quieter waters and the more persistent piling up of sediments.

The difficulty in correlating the different members of the Hastings Beds that occur underground, with the subdivisions recognised in the main Wealden outcrop, already commented on, is well exemplified in this section, and perhaps still better in the case of the next boring to be described (Pluckley, *see* p. 61). To attempt to correlate the single bed of sand of the Brabourne sequence with any of the great sand-banks that have been mapped out in the Weald would be mere conjecture.

Below the Hastings Series, we found at Brabourne an indubitable development of Purbeckian strata, though there was some difficulty in fixing the horizon at which this group should be

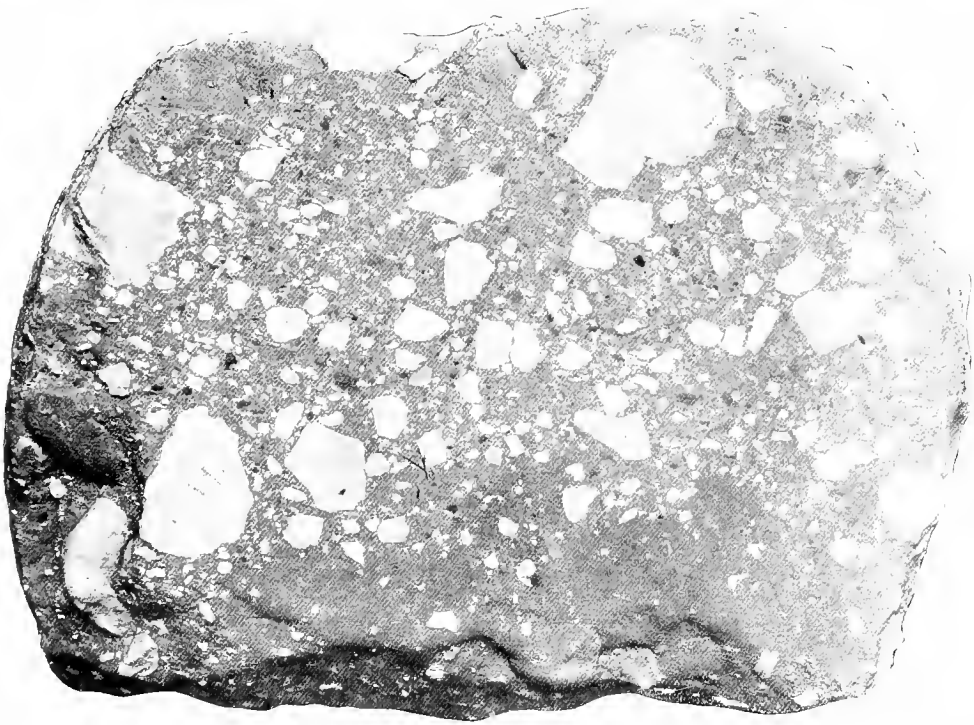
considered to have its upper boundary. For convenience, we have adopted the line at which, in the downward sequence, a strong green tint first became predominant in the bands of hard clay, but it was at 12 feet below this line that the first bed of unmistakable Purbeckian character was revealed.

The bed in question was a breccia of peculiar composition, about 3 feet thick, made up of scattered subangular fragments of pale mudstone and bits of lignite, embedded in a matrix of greenish muddy loam. Its general aspect is shown in the photograph reproduced in Plate II. We have seen a deposit of similar character in the Purbecks of the well-known Bugle Pit at Hartwell, in Buckinghamshire, where it fills irregular hollows of contemporaneous erosion in the underlying regular strata of the Purbecks, and is of such singular aspect that it has been mistaken for Glacial drift[1]. We also saw a few feet of the same kind of breccia (in 1904) among the Purbecks in a new cutting on the Great Central line ¼ mile west of Haddenham, near Thame, where it likewise rested on an uneven surface cutting the stratification; and it was noticed again a few miles further north-westward, in a very attenuated form, in the Purbecks of Brill[2]. In the two last-mentioned instances the breccia contained, as at Brabourne, fragments of thin shells not specifically identifiable, but almost certainly representing fresh-water or land forms. The origin of this singular deposit is problematical; its behaviour recalls the 'wash-outs' of the Coal Measures, and it may represent sudden local mudflows started on slopes of partly consolidated sediments by occasional heavy floods.

For 10 or 12 feet below the main band of this breccia at Brabourne there were occasional thin patches of similar material, alternating with hard green marly shales and compact blue-grey claystone flags; but the brecciated band mentioned at some 20 feet lower in the section was of a different nature, and appeared to be due to a local shattering of beds *in situ*. Among the ill-preserved fossils of this group of strata were two or three forms, notably *Corbula* and *Protocardia*, which indicate brackish water conditions. It is noteworthy that, as will be subsequently shown, the boring at Penshurst afforded definite proof of the occurrence of brackish water conditions about midway in the Purbeck Series (p. 73), so that we are able to recognise a 'Middle Purbeck' incursion of the sea in parts of Kent, as well as in Dorset; and to this phase we may provisionally assign the beds in question at Brabourne.

The lower part of the Brabourne Purbecks consisted largely of very hard smooth flaggy claystones that broke in sharp-edged conchoidal fragments, like flint. In structure these beds appear to be akin to the German 'Plattenkalk,' and they bear some resemblance to the Purbeckian rocks known as 'Pendle' in Dorset and elsewhere. Among the scanty fossils which they yielded

[1] "The Jurassic Rocks of Britain" (*Mem. Geol. Survey*), vol. v., pp. 224 and 279; subsequently corrected in "The Geology of Oxford," p. 63.
[2] "Geology of Oxford," *Mem. Geol. Surv.*, 1908, p. 63.



HAND-SPECIMEN OF PECULIAR BRECCIA IN PURBECK BEDS OF BRABOURNE BORING AT DEPTH OF 624–7 FEET.

Natural size.

were two impressions of insect wing-cases (from a depth of about 665 feet); and as these were obtained from the very limited area of a single seven-inch core we may surmise that a rich 'insect-bed' is present in the section.

Further information respecting the fossils from the Purbecks will be found in Chap. X., p. 145.

Portland Beds.

Immediately below the Purbecks, the Brabourne boring proved a group of marine strata, some 30 feet in thickness, that was wanting at Dover, but was represented in the borings at Pluckley and Penshurst farther westward, and was there much thicker than at Brabourne. The lithological and palæontological evidence shows conclusively that this group can be assigned to the Portlandian epoch; and when it is considered how far removed are the nearest outcrops of the beds of this age in England, the persistence of its characters is striking. Regarding the extreme top of the group we were unable to secure definite information at Brabourne, as this portion was not clearly displayed in the cores; but at Penshurst, where it was well seen, the junction with the Purbecks was quite sharp (*see* p. 76); and, so far as we could judge, the same condition obtained in the present boring. The base of the group at Brabourne was distinctly seen, and was accompanied by a sudden lithological change, with indications of erosion of the underlying Kimmeridge, but at Pluckley and at Penshurst the two formations merged almost insensibly into each other.

The sequence from the base of the Purbeck down to the top of the main Corallian Limestones at Brabourne was as follows:—

Section of Portland, Kimmeridge and Upper Corallian strata at Brabourne.

		Thickness. Feet.	Depth from surface. Feet.
	Purbecks, *see* last section (p. 38), to ...	...	680
Portlandian. 31 ft.	Greyish-yellow sandy limestone, with strong bituminous odour, containing *Serpula*, obscure casts of many large bivalves, including *Trigonia*, *Pecten*, *Ostrea*, &c., and a large ammonite (*see* list, p. 147); a band of hard crystalline nodular ferruginous limestone near the top, and another of pale yellow oolitic limestone just below it, with a layer full of *Pecten lamellosus* at 8 ft. from top; occasional disrupted partings, or pebbles, of shale; passing into calcareous sandstone toward base	11	
	Greenish-grey sandy mudstone and semi-indurated dirty calcareous sandstone, strongly bituminous, with *Serpula* and casts of bivalves	16	
	Calcareous conglomeratic-looking hard rock, strongly bituminous; with portion of a large ammonite, oysters, &c.; resting with a sharp junction on the beds below ...	4	... 711

		Thickness. Feet.	Depth from surface. Feet.
Kimmeridgian, 262 ft.	Dark clay or shale, very fossiliferous; ammonites, *Trigonia*, *Pecten*, *Ostrea*, &c. ...	8	
	Band of argillaceous limestone, probably nodular	1	
	Dark blue clay, rather shaly, with fewer fossils	5	
	Smooth pale bluish-grey or brownish calcareous mudstone with conchoidal marly fracture, alternating with bands of softer clay; fossils not abundant and often fragmentary except in occasional layers; chiefly small bivalves	35	
	Darker and softer marly clay, with well-preserved fossils, including large ammonites	14	
	Argillaceous limestone band with similar fossils	about 1	... 775
	Dark clays, as before, with traces of limestone bands or concretions...	8	
	Dark sandy limestone or calcareous sandstone with large crystals of calcite; containing large *Trigonia* and other shells, partly encrusted with pyrites ... ... (Some cores missing—probably clayey)	10	
	Similar rock-band at 10 ft. lower		
	Dark greenish and dingy grey glauconitic sandy loam, silty clay, and mudstone, with some ill-preserved casts of shells	47	
	Dark sandy limestone, some layers crowded with shells, *Trigonia*, &c.	about 2	
	Palish blue-grey clay, slightly sandy, containing ammonites and many shells, mostly small	43	
	Sandy limestone, grey sandy marl or clay, and bands of calcareous silty mudstone (part of cores not preserved); with some shells, mainly casts in poor condition ...	30	
	Firm smooth blue-grey calcareous clay with marly cuboidal fracture; fossils sparse, mainly in occasional layers	47	
	Band of greenish sandy and clayey limestone, shelly	about 2	
	Blue-grey marly clay, as before, with a band of shelly impure limestone at base... ...	9	... 973
Upper Corallian. (*cont. next page.*)	Greenish-grey glauconitic sandy mudstone, with black specks (thickness uncertain—some cores not seen)	about 4-6	
	Blue-grey marly clay, as before (only part of cores seen)	about 14	
	'Millet-seed iron-ore,' small shining brown globules of iron-carbonate crowded in a brown marly matrix, with casts of shells, and a few small lydites	3	... 996
	Blue-grey marly clay, passing down by alternations into hard smooth pale-grey marlstone or argillaceous limestone, slightly pyritous in places; fossils in a few layers, but elsewhere scanty...	40	
	Layers of coarsely-pisolitic pebble-like rubble, alternating with bands of grey marlstone and clay partings	4	
	Banded pale-grey marlstone or smooth argillaceous limestone, with few fossils	38	

		Thickness. Feet.	Depth from surface. Feet.
Upper Corallian, 162 ft.	Dark brownish-grey fossiliferous marl, passing down into—	31	
	Greenish impure sandy oolitic limestone, becoming coarsely oolitic in a 3 ft. band toward base	10	
	Dark brownish-grey fossiliferous marl, as before	16	
	resting on Corallian Limestone, at (*see* p. 46). ...	...	1,135

The Portland rocks of this section were separable into two divisions, the upper consisting essentially of limestones usually mixed in variable proportion with other components, and the lower of deposits in which sand was the chief constituent. At Penshurst, however, where the group was much thicker, this difference between the upper and lower parts, though still recognisable, was not so strongly marked, the beds being predominantly sandy throughout (p. 75). It will be shown in the palæontological part of this memoir that all the beds classed as Portlandian in the borings are probably equivalent only to the 'Portland Stone' division of Dorset, while the 'Portland Sands' of that area appear to be represented in Kent by clayey strata stratigraphically inseparable from the Kimmeridge Clay.

Fossils were fairly abundant in the Brabourne Portlandian, but mostly in the condition of casts; and as many of the specimens were of large size it often happened that only a portion of the fossil was contained in the cores, the remainder having been cut off by the circumference. The scantiness of our fossil list (p. 147) must not be supposed to imply poverty in the fauna, for we anticipate that if a shaft were sunk through these beds the palæontological harvest would be abundant. As it is, we obtained from this and the two more westerly borings a sufficient number of the characteristic species to establish the age of the series with certainty. An irregularly convoluted and knotted *Serpula* was the most conspicuous form of these beds in all three sections.

Both the limestone and the muddy sandstone were strongly impregnated with bitumen which had frequently exuded in brown pitchy drops and flakes along joints and other crevices. The substance had probably been distilled into these pervious beds from the overlying and underlying shales of the Purbeck and Kimmeridge. Its presence at this horizon suggests a probable source for the flow of natural gas from a well at Heathfield, in East Sussex, which has attracted much attention[1].

The Portlandian Series becomes much thicker as we go westward into the Weald from Brabourne, but maintains its lithological characters sufficiently to justify the assumption that there was not much variation of the depth of water in which it was accumulated at the three localities. It appears, therefore, to afford an indication of bathymetric level of which we can make use in discussing the wider results of the borings (*see* Chap. VII.).

[1] C. Dawson, "On the Discovery of Natural Gas in East Sussex," *Quart. Journ. Geol. Soc.*, vol. liv. (1898), pp. 564–571.

Kimmeridge Clay.

The 262 feet of strata which we assign to the Kimmeridge Clay at Brabourne consist of a heterogeneous group of deposits six times thicker than in the Dover section. In it we may trace the transition from the normal argillaceous type of the deep western basin to the anomalous glauconitic sandy type already described in the eastern section. Here we find an intercalation of both types; but the clays usually have a massive marly character, different from the shaly bituminous sediments of the deep basin; and the associated glauconitic loams, though less gritty than those of Dover, have again an aspect resembling that of the Sandgate beds in the Lower Cretaceous portion of the section.

The conglomeratic or brecciated appearance of the basement bed of the Portland Sands and the sharp lithological change to the clays of the Kimmeridgian are initial grounds for suspecting that the top of the latter series may have been pared down by erosion. This suspicion is confirmed by the palæontological evidence, which shows, however, that the loss has been less severe than at Dover, where only the 'Virgula Beds' or Lower Kimmeridge remain, and even these not in their entirety (p. 113). At Brabourne, as we shall be able to demonstrate from the fossils, the whole of the Virgula Beds are represented, along with about 64 feet of the higher part of the Kimmeridge; but the still higher beds recognised at Pluckley and Penshurst, where the sequence is complete, are absent, and, if ever deposited, have been destroyed by the pre-Portlandian denudation. At Brabourne, the Virgula Beds set in at 775 feet from the surface and continue downward to 973 feet, having, therefore, a thickness of 198 feet. The same zone expands to at least 340 feet at Pluckley (*see* p. 181), where the clays above this zone have a thickness of about 190 feet. The eastward attenuation, coupled with the erosion of the uppermost beds, has thus reduced the Kimmeridge beds at Brabourne by 270 feet or more in a distance of under ten miles.

In comparing the Brabourne sequence with that of Dover in respect to the composition of the deposits, we have a well-established basis in the peculiar 'millet-seed iron-ore' band, which is present in both sections in the Upper Corallian series. Working upward from this base, we find that the sections correspond in showing a preponderance of hard marly clays toward the bottom of the Kimmeridge Clay, but that these beds are more homogeneous at Brabourne and attain there an aggregate thickness of about 130 feet, while at Dover they are only 30 feet. The glauconitic loam, which comes next in upward succession in both sections, shows an expansion westward at almost exactly the same rate, being 10 feet thick at Dover and nearly 50 feet at Brabourne. Thus in these marine beds the results of the comparison are curiously analogous to those already yielded to us by the Wealden fresh-water beds.

Upper Corallian.

Between the Kimmeridge Clay and the Corallian Limestones at Brabourne there intervened a heterogeneous series of deposits,

presenting, though in varying degrees, most of the characteristics of the equivalent series at Dover. It will be needless to repeat the description; there are a few points of difference only which require mention.

The expansion of the series from about 100 feet at Dover to 160 feet at Brabourne is due entirely to the greater thickness of the bands of marly clay, which are also much less mixed with glauconite and grit than at Dover. The 'millet-seed iron-ore' bed, already mentioned as affording the best stratigraphical bond between the sections, is, on the other hand, much thinner at Brabourne; and the bands of pisolitic rubble so conspicuous both above and below this bed at Dover were noticed at Brabourne at the lower horizon only. The changes, in fact, are exactly those which denote quieter and somewhat deeper water at the latter locality, but the difference becomes less marked in the lower beds of the series. The fossils correspond with those found in the equivalent beds at Dover (for list and notes thereon *see* pp. 161-2). The prevalence of *Exogyra* of the *E. nana* type in the beds above the iron-ore is the main feature by which we discriminate between these strata and the overlying Virgula Beds of the Kimmeridgian.

Corallian Limestones.

With minor differences, the characteristic 'episodal' limestones of the Corallian at Brabourne resemble those of the Dover section, and the information yielded by the boring may be regarded as only supplementary to the more adequate data supplied by the shafts. The lithological similarity was close, except that there was apparently less admixture of clay at Brabourne than at Dover among the lower beds of the series, so that the purer pale limestones extended downward nearly to the base of the old reef. This difference appears to be due, not to an expansion of the upper pale beds, but to a slight change in the character of the lower beds, as the total thickness (134 feet) of the limestones at Brabourne is only 8 feet greater than at Dover. This relatively unimportant thickening of the Brabourne limestones is in striking contrast with the behaviour of the clays throughout the section, and is a factor to which we shall revert in a later chapter.

We could not expect, of course, to find fossils as plentiful in the cores as in the tip-heaps from the shafts, and there was little chance of obtaining the big handsome gasteropods that were so conspicuous at Dover, but the fauna at the two places is probably identical. A list of the fossils is given in Chap. X., p. 162.

These Corallian Limestones must have been accumulated at approximately the same bathymetric level in the two localities, and when considered in conjunction with analogous deposits at other stratigraphical horizons in the sections they afford us a most significant index to the relative displacements of the areas in the past. (*See* Chap. VII.)

The following section shows the downward succession from the top of the Corallian Limestones to the base of the Kellaways Rock.

Section of Corallian Limestones, Lower Corallian, Oxford Clay and Kellaways Rock at Brabourne.

		Thickness. Feet.	Depth from surface. Feet.
	Upper Corallian marl, &c. (*see* p. 43), to	...	1,135
Corallian Limestones 134 ft.	Pale yellowish-grey limestone with slaty-blue streaks; hollows filled with crystalline calcite; some crumpled clayey partings: with lumpy uneven fracture and with dense horny blue-hearted masses in a pale soft limestone-matrix in places: corals and *Cidaris*-spines occasionally abundant: passing down into—	67	
	Pale cleaner limestones of Coral Rag type...	58	
	Similar limestone with increasing intercalations of marl	9	... 1,269
Lower Corallian Series, 46 ft.	Pale smooth slaty-grey or brownish calcareous clay and claystone, slightly sandy in places, with cuboidal marly fracture ...	11	
	Thin bands of clay full of ferruginous oolitic grains, alternating with hard marl with similar grains, the clay increasing into preponderance downward: ammonites, a large dilatate oyster and many ill preserved bivalves: passing down into—	±35	... 1,315
Oxford Clay, 173 ft.	Pale smooth blue-grey clay with marly structure: including some fossiliferous semi-indurated claystone bands containing many *Pecten*, *Modiola* and other bivalves, but fossils otherwise sparse except in a few bands. (These are the general lithological characters, but the beds were not examined in much detail): passing down into—	±173	... 1,488
Kellaways Rock (? with Cornbrash), 18 ft.	Dark grey calcareous sandstone, intercalated in the lower part with impure limestones, ferruginous and ironshot layers, bands of fragmental-looking green loam, and thin shaly partings: with a well-defined base on whitish calcareous grit (*see* p. 48), at	±18	... 1,506

Lower Corallian and Oxfordian.

Between the limestones of the Corallian and those of the Lower Oolites there intervened at Brabourne, as at Dover, a thick mass of predominantly clayey sediments, which formed an unbroken sequence difficult to subdivide. That the major portion was equivalent to the Oxford Clay was rendered certain both by the stratigraphical and by the palæontological evidence; the presence of the Kellaways Rock at the base was likewise established, and the uppermost part might be classed with confidence as Lower Corallian. But the boundaries adopted for these subdivisions in the section given above are more or less arbitrary.

The whole succession between the great limestones of the Corallian and of the Lower Oolite was very little thicker at Brabourne than at Dover—only some 8 feet; but the two sections showed much variation in detail, and the correlation of individual beds was much less easy than in the higher formations. It may be noted generally that the clays occurred in thicker and more

homogeneous masses at Brabourne, and were less interrupted by stone bands or other variation. On the other hand, the rubbly beds of the Lower Corallian and the sandy bed of Kellaways Rock were barely half the thickness of their Dover equivalents. The top clay-band of the Lower Corallian was of the same character and thickness in both sections; but below this the differences become marked, and it is probable that there is a lateral change in the character of the sediments, so that the more variable deposits of Dover are in part replaced by beds of homogeneous clay at Brabourne. The Oxford Clay itself has increased to nearly twice the Dover thickness at Brabourne, and thus more than counterbalances the reversed proportions of the series above and below it.

Our examination of the monotonous cores of clay in this part of the Brabourne section was perhaps hardly patient enough to disclose minor diversity of structure, but we are satisfied that the conspicuous variations of colour and composition noted in the Dover section were not present here, though our palæontological work shows that the sequence of the fossil-zones was the same.

Owing to the difference in the Kellaways-Cornbrash development at the two places, this portion of the succession was not easy to correlate, but we consider that a bed of whitish calcareous grit at the base of the darker impure sandstones is probably equivalent to the band of pale limestone classed as the topmost bed of the Forest Marble in the Dover sequence (*see* section, p. 28). If this be so, any equivalent of the Cornbrash that may exist at Brabourne must lie above this horizon, but was practically indistinguishable from the Kellaways group; it may find place among the thin shaly layers with impure limestones and 'iron-shot' bands noted in the base of the dark sandstones. It should be mentioned, however, that the cores were broken and imperfect at this horizon, so that our information may be at fault; indeed, the occurrence of the 'fragmental-looking green loam' among the lowest material renders it possible that we may have included the top of the Forest Marble Series in the above section, as we found the presence of green beds to be indicative of this series at Dover. Unfortunately, the palæontological material was also too scanty to enable us to fix the base of the Middle Oolites here with certainty.

Lower Oolites.

Continuing the downward succession from the base of the last-described section, we reach a group of deposits consisting mainly of fine-grained Oolite limestones undoubtedly belonging to the Great Oolite division, with variable strata above and below them, which are more difficult to classify, but which probably include representatives of the Forest Marble Series above, and of the Fuller's Earth and Inferior Oolite divisions below.

The cores in this part of the boring had a diameter of 4 inches down to a depth of 1,550 feet from the surface, and of 3 inches below this depth. After the boring was finished they were broken up systematically in the search for fossils, but with comparatively

scanty result, many of them proving to be practically devoid of identifiable organisms.

Our classification of the Lower Oolites down to the top of the Lias is shown in the following section:—

Section of Lower Oolites at Brabourne.

		Thickness. Feet.	Depth from surface. Feet.
	Kellaways Rock (? with Cornbrash), to	...	1,506
Forest Marble Series, 13 ft.	Greyish-white calcareous sandstone, with bitumen-stained joints; containing ill-preserved lamellibranchs, brachiopods and serpula; passing down into sandy limestone, with a brecciated shaly parting near the base	7	
	Greenish-blue sandy shale, with traces of oolitic structure and thin intercalations of rather muddy oolitic limestone at base	6	... 1,519
Great Oolite Limestones, 114 ft.	Pale greyish fine-grained oolitic limestone, sparingly mixed with grit and clay in places: containing a few shells, mainly in clayey layers	49	
	Cream-coloured sandy limestone or fine calcareous sandstone, passing down into—	7	
	Cream-coloured oolitic limestone; very few fossils	25	
	Greyish fine-grained oolitic limestone, rather sandy: with small shells abundant in places: *Placunopsis jurensis*; *Pseudomonotis*; *Pecten*, &c.	33	... 1,633
? Fuller's Earth Series, 23 ft.	Dark grey or bluish calcareous shales, with pyrites and some ill-preserved shells, *Astarte*, *Pteria*, &c.; toward the base interbedded with thin brecciated bands of limestone, and passing down into—	23	... 1,656
? Inferior Oolite, 44 ft.	Grey-blue somewhat muddy oolitic limestone of medium texture; becoming paler grey below; apparently unfossiliferous: with a pebbly-looking or brecciated layer at the base:...	44	
	on Upper Lias shale (*see* p. 50), at ...	...	1,700

Granted that the uppermost bed of this section be equivalent to the top bed of the Forest Marble Series at Dover, we may trace a rough correspondence in the succession down into the Great Oolite limestones, though with differences in detail. The main limestones were much thicker at Brabourne than at Dover, and the beds below them were so different in character that the correlation of this portion becomes uncertain.

At Dover, as we have seen, the limestones grew increasingly sandy downward, and had a mass of unfossiliferous sand at their base, the sequence being very similar to that in Bas Boulonnais. But at Brabourne all affinity to the French type was lost, and in its place there was an approximation to the conditions at corresponding horizons in the West of England. The main limestones were underlain by a belt of calcareous shales, recalling the Fuller's Earth Series of the West; and beneath the shales another limestone, over 40 feet thick, was found, which unfortunately yielded no fossils, but may be assumed to represent part of the

Inferior Oolite of the West. This lower limestone seemed to have a brecciated or nodular base resting directly upon the Upper Lias shales, but the junction was not clearly seen in the cores.

It is questionable whether the lower sands of Dover should be regarded as equivalent to the shales and lowest Oolite limestone of Brabourne, or as a replacement of part of the Great Oolite limestones by sandy shore-deposits. The latter view would partly explain the expansion of the main limestones at Brabourne, where they are 114 feet thick, or nearly twice their thickness at Dover; and it would further imply that the increased thickness of the Lower Oolites at Brabourne is due mainly to the presence of some 60 or 70 feet of lower Oolitic strata than are present at Dover. The lithological break at the base of the Oolites was sharply defined in both sections, and in each case the sequence is discontinuous at this horizon. It evidently denotes a period of important physical changes in the region.

Lias.

Interesting in every part, the importance of the Brabourne boring from the scientific standpoint culminated in the portion which remains to be described. This portion is, moreover, of peculiar importance from the fact that the results were such as are unlikely to be again attained in the commercial underground exploration of Kent, the proved absence of the Coal Measures having driven the operators northward into the region of thinner and less complete Mesozoic sediments. Though the Lias has been recorded as occurring in some of the more northerly borings[1], its thickness in them appears to be relatively slight, while the explorations farther westward have failed even to reach the Lower Oolites owing to the vast thickening of the superincumbent strata. The Brabourne section of the Lias is therefore likely to remain the fullest that we can expect to obtain in Kent; and the strata below the Lias in this boring may not be reached again in the county, at any rate by coal explorations.

We find ourselves, unfortunately, in some doubt as to the thickness of the formation in the boring. The notes recording our personal examination of the cores in 1898 give the thickness of the formation as 140 feet, ranging from the depth of 1,700 feet to the depth of 1,840 feet; but in the summary of the section published by the late R. Etheridge in 1899[2], the thickness is stated to be 172 feet 9 inches, and the range of depth is carried down to 1,874 feet; and among our Liassic fossils collected in 1898 are a few to which the depths of 1,861 to 1,868 feet are assigned. It is mentioned, however, in our notes that only a small portion of the thickness of the red marls underlying the Lias was represented in the cores drawn from the boring, the greater part having crumbled away. If the missing cores were not allowed for in

[1] W. Boyd Dawkins, *Final Rep. Roy. Comm. Coal Supplies*, 1905, pt. x., pp. 29–33 (Ropersole and Ellinge). "The Water Supply of Kent," *Mem. Geol. Surv.*, 1908, pp. 223–225 (Waldershare and Fredville).

[2] *Rep. British Assoc.* for 1899 (1900), p. 733.

measuring upward from a lower depth, the base of the Lias would inevitably be reckoned too low; and we think it probable that some mistake of this kind has been made, especially as our specimens marked with the lowest depths correspond exactly with beds higher in the sequence. We have therefore considered it safest to trust to our original notes of the depths. This entails giving a greater thickness than previously to that unique feature of the Brabourne section, the Triassic deposits.

The cores in this part of the boring had a diameter of 3 inches, and as many of the beds were fairly rich in fossils we were able to collect sufficient palæontological evidence to prove the presence of all three divisions of the Lias (*see* lists and full discussion, pp. 170-8). The section, according to our notes, was as follows:—

Section of the Lias at Brabourne.

		Thickness. Feet.	Depth from surface. Feet.
	Lower Oolite limestone, to ... ... (*see* section, p. 48).	...	1,700
Upper Lias, 15 ft.	Smooth blue shale	3½	
	Reddish-brown band of indefinite character and insufficiently seen in the cores; resembling a broken-up clay-bed or shaly conglomerate	½	
	Smooth blue shale, as above, with crushed ammonites and other fossils (*see* list p. 170)	11	... 1,715
Middle Lias, 45 ft.	Dark green pyritous sandy rock like Marlstone, with bitumen-stained joints and small cavities filled with crystalline calcite: containing brachiopods and small lamellibranchs: passing down into—	14	
	Greenish-grey limestone, brecciated and crystalline in places: full of *Rhynchonella*, &c.	17	
	Dark greenish-blue micaceous shale, very fossiliferous: passing down into— ...	9	
	Ferruginous limestone or calcareous ironstone, with ironshot grains and rusty markings: worn pebbly-looking ferruginous lumps or nodules up to 1½ inch diameter in a well-marked band 6 inches from the top: fossils abundant, including large *Pecten*, *Lima*, &c.	5	... 1,760
Lower Lias, 80 ft.	Grey smooth clay with cuboidal marly fracture, slightly sandy in places, with occasional brown nodules: crushed imperfect fossils, becoming abundant toward the base, including ammonites, belemnites, pentacrinine fragments, &c. (*see* list p. 173) ...	60	
	Greenish-grey sandy shale, somewhat ferruginous, with ironshot grains and rusty casts of fossils: passing down into—		
	Greenish and blackish mottled sandy rock and muddy ferruginous limestone, with patches of calcite: at the base, a band of brown ironshot muddy sandstone: some fossils, including *Belemnites*, *Rhynchonella*, *Lima antiquata*, &c. (*see* list p. 177)	20	
	said to rest on Red Marl (Trias) at ... but no cores drawn for the next 5 ft.	...	1,840

It will be noticed from the above section that, as at Dover, the usual lithological characters of the different divisions of the English Lias are preserved in this area almost throughout the sequence, in spite of its great distance (about 120 miles) from the nearest outcrop, and in spite of the remarkable condensation of the deposits which in Dorset range up to 900 feet in thickness and in Yorkshire to 1,100 feet. The blue shale of the Upper Lias, the sandy ferruginous limestones and micaceous shale of the Middle Lias, and the grey clays and shales of the main portion of the Lower Lias maintain the typical features of these divisions, and show how wide-reaching were the successive changes of condition in the British Liassic seas.

The ferruginous rock at the base of the Lower Lias, however, is less normal. So far as we could judge, it rested directly upon the Triassic Marl, without the intervention of the Rhætic. As it is known that the Lias at Dover and in other Kentish borings[1] lies unconformably on the Coal Measures, this lowest bed marks the transgression of the early Mesozoic sea upon a denuded land. The extent of the unconformity is perhaps indicated by the fossil-evidence (*see* p. 177) which suggests the absence of the lowermost zones of the Lias. It is no doubt accompanied by some discordance of bedding, though this was not directly visible in the cores which, as already mentioned, were very imperfect for the first 20 feet or so below the Lias. The discordance however is probably not great, as the dip of the red marls and conglomerate, so far as their bedding could be observed in the limits of the cores, was slight and not appreciably higher than that of the Lias.

Most of the beds of the Brabourne Lias appear to have a thickness from three to four times that of their probable equivalents at Dover, after every allowance has been made for the portions of the sequence that are wanting at Dover.

This attenuation and some other features point to the deposits having been laid down at no great distance from the margin of the Liassic sea. The proximity of land and the effect of off-shore currents have evidently been the determining factors in the development of the Kentish Lias, as in most of the subsequent Jurassic sediments of the county.

Trias.

The imperfect state of the cores for a little distance below the base of the Lias precluded any actual examination of the immediately underlying strata; but from the colour of the washings there can be little doubt that marls of Triassic character set in suddenly beneath the ferruginous Liassic rock-band and that transitional strata of the Rhætic type were absent.

The fragmentary cores drawn at 6 or 8 feet below the junction consisted of hard lumpy yellowish-mottled marl without trace of bedding, and with an irregular broken appearance which may have been due to the action of the boring tools, but raised the

[1] Ropersole, Ellinge, Waldershare and Fredville, *see* footnote on p. 49.

conjecture that the top of the marl may have been affected by pre-Liassic weathering. Lower down, the material became firmer, yielding some good cores; and here the red colour became predominant and the marls showed occasional bedding-planes marked by sandy or gritty streaks, which did not diverge noticeably from the bedding-planes of the Jurassic deposits, being not far from the horizontal. No fossils were found in these beds.

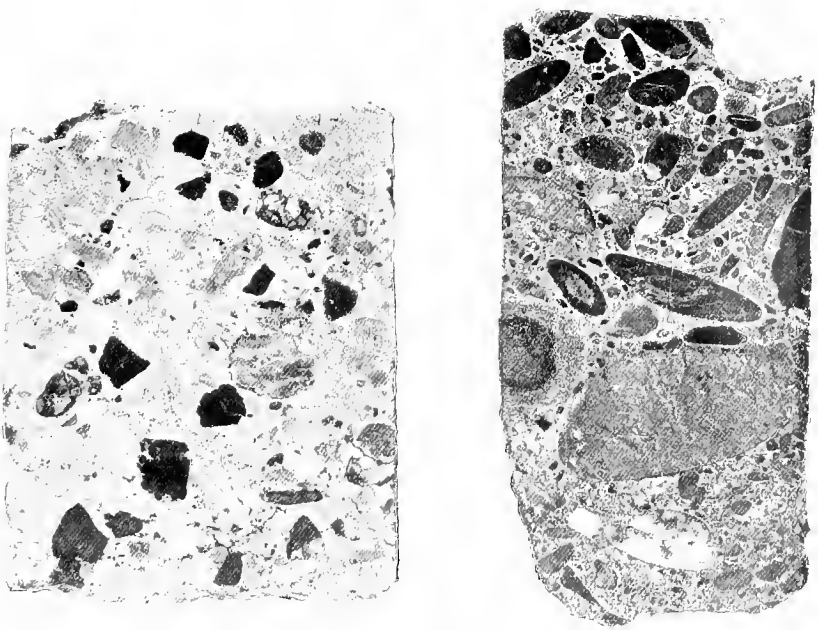
By an increase in the thickness and coarseness of the gritty layers the marls passed gradually downward into the pebbly conglomerate forming the base of the Mesozoic sequence. The boring in this conglomerate was reduced to a diameter of 2 inches, but fortunately gave excellent solid cores, the pebbles being firmly set in the matrix. The rock is extremely interesting, for the pebbles indicate the character of the Palæozoic rocks which were exposed to erosion at this period. Two varieties of it are illustrated in Plate III., from photographs of sliced cores.

About half the pebbles are of limestones of various kinds, many being of a compact opaque-whitish horny-looking variety, while others are red or pinkish, probably due to subsequent staining, and others bluish-grey, with a few of darker tints. The columnals of a very small crinoid are visible in two or three of the limestone pebbles in our collection; and in the microscopic slides of these and other specimens obscure traces of other organisms and ramifying tubules resembling the borings of minute sponges are abundant, but we have not succeeded in obtaining from them any fossils clearly indicative of their age. One of the sliced limestones shows a very definite oolitic structure, such as is occasionally present among Carboniferous limestones. The pebbles are very slightly, if at all, dolomitised, as they effervesce freely under cold weak acid. The largest limestone pebble in our collection exceeds the diameter of the core (2 inches), and, like most of the fragments, is rounded. Many of the pebbles range between 1 and 2 inches in diameter.

While it is highly probable that these limestone pebbles have been derived from a not far distant outcrop of Carboniferous limestone[1], there does not seem yet to be any certain indication of the age of the rocks from which they were derived, and their variety may imply that they are of more than one age. The pre-Carboniferous age of the Palæozoic rock immediately underlying the conglomerate at Brabourne seems beyond doubt; and when we remember the great variety of Palæozoic formations which are known to be covered by the Mesozoic rocks along the northern margin of Bas Boulonnais, among which are included some thick limestones of Devonian age, it is necessary to bear in mind the possible existence of limestones older than the Carboniferous on the buried Palæozoic floor of Kent. It should be added, however, that the presence of the Carboniferous limestone has been recently reported in certain of the later borings.

The other pebbles of the conglomerate have yielded us little further information. Fragments of chert, mostly small flaky

[1] This opinion has been stated by Prof. W. Boyd Dawkins, and is adopted in the account of the Brabourne section given in "The Water Supply of Kent," *Mem. Geol. Surv.*, 1908, p. 223.



SPECIMEN-CORES, SLICED AND POLISHED, OF TRIASSIC CONGLOMERATE FROM DEPTH OF 1,889–1,921 FEET IN BRABOURNE BORING.

Angular black patches in left-hand specimen are fragments of dark chert.

$\frac{4}{5}$ Natural size.

more or less angular chips, sometimes almost black but more often of a jaspery red tint, are abundant; our slices of this material have failed to reveal any trace of organisms. The red and grey quartzites, grits and sandstones seem all to be such as are found commonly in Triassic conglomerates, and give no indication of their origin; the largest in our collection is a partly rounded pebble too large to be wholly included in the 2-inch core, but the majority are about an inch in diameter. No fragments of igneous rocks have been detected; and it is noteworthy that although Coal Measures have been proved to occur immediately below the Lias in the borings to the north-eastward, we were unable to recognise any detritus from this formation in the conglomerate.

The obvious correlation of the Brabourne pebble-bed with the Dolomitic Conglomerate which occurs at the base of the Trias in the Mendips and South Wales has been previously recognised and generally accepted. Its origin as a shore-deposit of the Triassic inland sea or salt lake in Keuper times is a necessary inference from this correlation. The general similarity of sequence and structure in the rocks of the Mesozoic basin of Southern Britain is thus traced back almost to the beginning of Mesozoic times.

The presence of Trias in this part of the country was nevertheless unexpected. The nearest outcrop lies 140 miles distant north-westward, so that the discovery of the formation in the boring constitutes a very welcome addition to our knowledge of its range. From the marginal character of the pebble-bed, and from the known relationships of its equivalent, the Dolomitic Conglomerate, in the western region, we are justified in the conjecture that this section has revealed to us the northern fringe of a formation which may attain much greater thickness in the area to the southward. The conjecture is, unfortunately, never likely to be proved by actual exploration; but if accepted it implies a further addition to the prolonged piling up of sediments in a single basin of depression which is so remarkably exemplified in all these Kentish borings.

There is no outcrop of Trias in Bas Boulonnais, and borings have proved its absence underground over the greater part of that region. Its presence was suspected however in a deep boring at Framzelle, near Cap Gris Nez, which, before entering Silurian rocks, passed through marls (predominantly red in colour), grit and conglomerate, and in another boring at Pas-de-Gay, where grey and red grit and red clayey shales were found between the Oolites and the Silurian[1]. The succession at Framzelle reads very like that of Brabourne, and this discovery of the Trias on the English side of the Channel will strengthen the French investigators in their recognition of the formation.

The downward sequence at Brabourne from the top of the Trias to the bottom of the boring is summarised in the following section.

---

[1] Gosselet, "Aperçu General sur la Geologie du Boulonnais," quoted in "Bassin Houiller du Boulonnais," par A. Olry (Gites Mineraux), p. 48.

Trias and underlying Palæozoic rocks at Brabourne.

		Thickness. Feet.	Depth from surface. Feet.
	Lower Lias: to... ... ... (*see* section, p. 50).	...	... 1,840
Trias 81 ft.	Red Marl reported, but did not make a core	5	
	Mottled purple and greenish-yellow brecciated-looking marl, with small roundish cavities suggesting removal of a soluble constituent: only small portions of core recovered	8	
	Marls of variable colour, greenish- and yellow-mottled, greenish, and deep red (red colour very deep in lower part), with sandy bands and layers of fine grit toward base	36	... 1,889
	Red and grey conglomerate of well-rounded and partly-rounded pebbles of limestones of several kinds, red and grey quartzites, limy sandstone, and red and black chert, in a matrix, sometimes scanty, sometimes abundant, of red and grey gritty marl, and occasional irregular intercalations of similar marl: yielding good cores: the pebbles mostly small, but ranging up to over two inches in diameter:	32	
	resting with a sharp unconformity on —(cores much broken, for a few feet below the junction)— ...	...	... 1,921 [1]
? Devonian or older.	*Palæozoic strata of undetermined age.* Fine-grained homogeneous silty shale or massive mudstone, stained dull red and purple, with greenish streaks, in the upper 20 ft., but becoming dark sooty grey or nearly black below; showing traces of wavy bedding-stripe in places at an angle of 20° to 30° to the horizontal axis of the cores, and with a slight cleavage at about 60°: making excellent cores: the only fossils found were a ribbed shell (? Rhynchonellid), at 30 ft. above bottom of boring, and indistinct traces of organisms at slightly lower levels	83+	
	Boring ended at	...	... 2,004 [1]

Palæozoic Strata of doubtful Age.

We can add little to the description given in the foregoing section of the oldest rocks of the boring. They were of the same unvarying composition down to the bottom, differing only in tint, the red colour of the upper part being evidently the result of secondary staining. The cores were fragmentary for a few feet

[1] These figures differ by 2 or 3 ft. from those of our notes: they have been altered to bring them into agreement with those of Etheridge's second record, published in *Final Rep., R. Comm. Coal Supplies* 1905, pt. x., p. 30, as it is undesirable to vary the reading when the matter is of no real consequence.

below the base of the Trias, probably indicating a zone of ancient weathering, but below this they were drawn in long smooth cylinders, 1½ inches in diameter, showing admirably the close-grained unfractured character of the rock. The red staining faded out gradually in the first 20 feet, but recurred in a few streaks among the dingy grey rock at lower levels. The examination of a microscopic slide of the rock showed it to be composed essentially of fine siliceous grains set in a rather scanty matrix of ill-defined dusty siliceous and clayey substances with traces of iron. A rough chemical examination indicated that the rock also contained a trace of carbonaceous matter. It has been, in fact, originally a silty mud, and might now be called, alternatively, a compact fine-grained clayey sandstone: a massive sandy claystone: or an imperfect slate. In the borer's Journal it was at first called a "sandy marl" in consequence of its homogeneous character.

The bedding stripe was very indistinct, and could only be distinguished in a few of the lower unstained cores, where it was indicated by slightly darker and lighter streaks which were somewhat crumpled and dragged, probably by slight movement parallel to the planes, as is so common in ancient rocks of this type. The cleavage was likewise ill-defined, but was sufficient to cause the rock to fracture more readily along it than in any other direction.

We searched the cores of this rock for fossils without result until they were systematically broken up by our assistant, Mr. J. Rhodes, who succeeded in obtaining, along with some obscure traces, a single specimen which is recognisably the shell of a marine form, possibly of a Rhynchonellid. Vague though this may be, it is of consequence as indicating that the formation is of marine origin, a point on which we were previously in doubt.

The beds bear no resemblance in structure or composition to the Carboniferous rocks proved in other Kentish borings. They are evidently older than the Coal Measures, and presumably are older than any part of the Carboniferous system. They have been assigned to the Devonian in previous accounts of the section[1], but there is nothing in the evidence to prove definitely that they are of this age, and it is within the range of possibility that they may be older. It is not unlikely that, as in the previously discussed case of the limestone pebbles in the overlying conglomerate, more definite information might ensue from a searching comparison with the Palæozoic rocks outcropping at the margin of Bas Boulonnais, as these are probably on the line of strike and are the nearest pre-Carboniferous rocks reaching the present surface.

We may mention that we have compared[2] the slaty rock of Brabourne with the bottom rock reached at a depth of 1,029 feet in the deep Harwich boring, and find that there is a close

[1] W. Boyd Dawkins, *Final Rep. Roy. Comm. Coal Supplies*, 1905, pt. x., p. 30.

[2] On the suggestion of our former colleague, Prof. W. W. Watts, F.R.S.

resemblance between them. It will be remembered that the Harwich rock was originally supposed to be of Carboniferous age, on grounds which proved to be untrustworthy[1]. Like the Brabourne deposit, it is known to be of marine origin, but its age remains doubtful. In other deep borings in East Anglia—at Sutton in Suffolk, and at Weeley in Essex—Palæozoic rocks similar to those of Brabourne were reached at depths of 994 feet and 1,094 feet respectively, but again without yielding proof of age[2].

[1] *Ann. Rep. of Geol. Survey for 1896*, pp. 5–6.
[2] *Rep. British Assoc. for 1895*, p. 693; and *Essex Naturalist*, vol. x., 1897, p. 137.

CHAPTER IV.

THE PLUCKLEY SECTION.

General Notes.—The site of the Pluckley boring lies 9¾ miles W4°N. from that of Brabourne and 23½ miles W5°N. from the Dover shafts, in the field adjoining the northern side of the South Eastern Railway 200 yards east of Pluckley Station, at a height of about 105 feet above Ordnance Datum. The boring was begun in the early summer of 1897 and was suspended in the spring of 1900 at a depth of close upon 1,700 feet. The site is on the outcrop of the Weald Clay, at about a mile within the northern boundary of the formation, and therefore at a horizon estimated to be about 130 feet below the top of the Wealden strata. But although the boring thus began in beds which lie about 350 feet below the surface at Brabourne, and 450 feet deep at Dover, the thickening of the Wealden and Upper Jurassic deposits proved to be so great that the base of the Kimmeridge Clay was not reached in the section.

While the work was in progress we visited the boring at intervals and collected the information and specimens on which the following account is based. The contractors encountered many difficulties and mishaps in making the boring; and from the imperfection of the cores and their small diameter in the lower part of the section, the material available for study was frequently inadequate. It was therefore not possible to investigate all parts of the succession closely, and the opportunity for collecting fossils was very limited. Sufficient information was obtained, however, to prove the order of the deposits and their leading lithological and palæontological characters, and to enable us to correlate and compare them with their better-seen equivalents in the other sections.

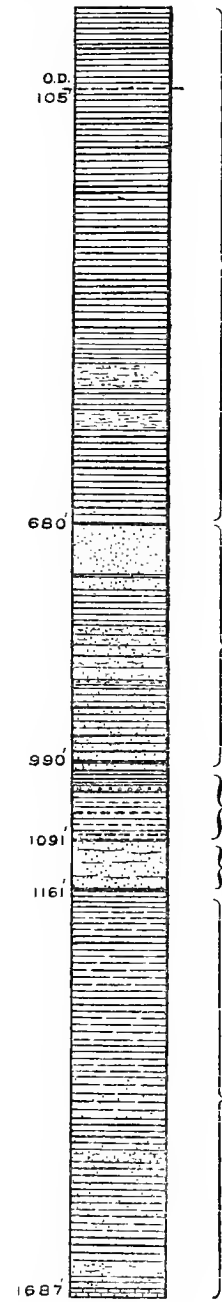
The upper 420 feet of the boring was worked with chisel-tools, yielding mixed and fragmentary material only; the cores immediately below this depth had a diameter of 6 inches where they could be drawn intact, but were often imperfect, or wanting, in the softer beds. Below 800 feet the diameter of the cores was 4 inches; below 1,000 feet, 2½ inches; and below 1,500 feet, 2 inches. The clays, silts and shales which comprised the major portion of the strata often proved perishable when exposed to the air, the cores taking up moisture and soon disintegrating, so that unless examined when fresh, the opportunity of collecting fossils from them was lost.

The dip of the beds throughout was too slight to be measured in the cores, except that crumpled beds occurred here and there, due to local disturbances, which did not affect the general horizontality of the strata.

The only previous account of this boring is a summarised section, from the MS. notes of the late R. Etheridge, published in the Final Report of the recent Commission on Coal Supplies (pt. ix., 1905, p. 48). In this publication the presence of the Purbeck and Portland beds is not mentioned. The same account is used in "The Water Supply of Kent" (*Mem. Geol. Surv.*), 1908, p. 235.

FIG. 4.—PLUCKLEY: SUMMARISED SECTION OF THE BORING.

Scale: 1 *inch* = 250 *feet:* (*same as Figs.* 2 *and* 3).



	Thickness. Feet.
Weald Clay (incomplete at top); ... ... for details, *see* p. 59.	680
Hastings Beds; ... ... for details, *see* pp. 59–60.	310
Purbeck Beds; ... ... for details, *see* p. 60.	101
Portland Beds (sandstone); ... ... for details, *see* p. 64.	70
Kimmeridge Clay; ... ... for details, *see* p. 64.	526+

The beds above the Portlandian constitute an unbroken sequence of fresh-water strata, with possibly an estuarine phase toward the base. In this sequence we can recognise the amplified equivalents of the main divisions present at Brabourne. The boundaries adopted for these divisions are, however, more or less arbitrary, being based on lithological characters which are seldom sharply defined. In most cases, therefore, only the broader features of the correlation can be followed, as comparison in detail might be misleading. A generalised section of the beds is shown in Fig. 4. The following further description and comment are arranged as in the preceding chapters.

The Wealden and Purbeck Section.

Wealden and Purbeck at Pluckley.

		Thickness. Feet.	Depth from surface. Feet.
	Surface at about 105 ft. above O.D.		
Weald Clay (? with top of Hastings Beds), about 680 ft.	Clays, partly blue and grey, partly of red and mottled variegated tints, down to 246 ft.; and mostly dark-blue below, down to 420 ft.; worked through with chisel-tools, and therefore only fragmentary material seen; fossils appear very scarce, except in occasional calcareous rock-bands: *Cyrena*, *Viviparus*, and fragments of fish	420	... 420
	Dark grey sandy mud, partly indurated, yielding cores in upper 10 ft.; then, silty clay giving no cores; then, mainly red mottled silty clays and banded grey, blue and brownish clays with few or no fossils except in 5 ft. darker silty clays at depth of about 480 ft., which contain many plant-remains, carbonaceous streaks and lignite...	92	
	Grey muddy or silty clays	43	
	Grey and greenish striped and laminated shaly clay and silt, with layers of fresh-water shells; occasional nodules of clay-ironstone and some bands of tough black clay	45	
	Dark laminated hard clay or shale, streaked with pale shelly layers crowded with *Cyrena*, cyprids, &c.	10	
	Banded pale grey, dark grey, dark brown, and black silty beds, in part shaly and in part mixed and dappled with bedding obscure; occasional layers or nodules of septarian clay-ironstone; plant- and fish-remains here and there. No cores of lower part	70	... 680
Hastings Beds (*cont. overleaf*).	Fine grey sand, rather muddy; yielding no cores and seen in washings only	about 66	
	Grey marly clay with lignite (not seen) ...	4	
	Grey sand or soft sandstone; yielding no cores	15	... 765
	Dark grey clay and some red mottled clay, with pyrites and ironstone nodules; hardly any core obtained	46	
	Grey sandy clay with plant-remains and a curious pale-grey pisolitic-looking marly band: *Cycadites saportae*, *Sphenopteris fittoni?*	11	

		Thickness. Feet.	Depth from surface. Feet.
Hastings Beds, about 310 ft.	Mottled red and grey pyritous clay; brownish silty clay with nodules; and grey and bluish silty and sandy clays, partly indurated with a concretionary structure; cores very imperfect, and only small portion seen	51	
	Dark bluish-grey clay with pyrites and clay-ironstone nodules; at the base a 4-in. band of hard claystone with excellent cone-in-cone structure	8	
	Grey sandy and silty clay, slightly mottled with red in places; dull brown clay; pale grey and greenish marly clay with yellow, orange, purple and rusty-brown mottling; rather shaly dark grey clay, slightly mottled, with obscure fossils (*Cyrena?* &c.); and pale purplish and grey clay with bright red and yellow mottling, and massive marly structure; cores mostly imperfect, showing only portion of section	82	
	Dark grey, nearly black, shaly clay, with fish scales, &c.; and paler grey silty clay; cores in part only	12	
	Smooth black shale approximating to Purbeck type, and some pale purplish and grey clays; very little core obtained	15	... 990
Purbeck Beds, about 101 ft.	Dark green shaly clay, with crushed slickensided structures; passing down into darker greenish-grey shale with pyrites and nodules; very little core obtained from lower part	17	
	Dark sandy conglomeratic clay, with pebble-like fragments of dark shale, up to ½-in. diameter, and obscure traces of shells; only one-third represented in cores ...	about 7	... 1,014
	Alternations of pale grey and dark greenish-grey indurated clay or marl; smooth, compact and flaggy; with partings of blackish shale; yielding some good cores	22	
	Band of pale grey or whitish marlstone, passing down into similar marlstone of beautiful pale green tint; with alternations of pale grey and duller grey bands below ...	16	
	Peculiar hard close-grained clayey limestone, crowded with dark oval bodies, probably minute phosphatic concretions (a similar rock occurs near this horizon in the Penshurst section)...	2	... 1,054
	Alternations of pale and dark greenish-grey flaggy calcareous claystone; good cores ...	9½	
	Gypsiferous rock-band...	1½	
	Banded smooth calcareous claystone-flags, with compact splintery fracture, containing pyritous layers, beds of brownish-grey cement stone, and some gypsum; sparingly fossiliferous: cyprids, *Cyrena?* &c. ...	12	
	Gypsiferous beds; bands and veins of gypsum in much-crumpled and disturbed shales and cement-stones with strong bituminous odour; good cores except at base, where there is apparently some calcareous grit, but lowest 2 or 3 feet not seen ...	about 14	
	on Portlandian (*see* p. 64), at ...	...	1,091

Weald Clay.

The section begins below the horizon of the dark blue shaly clays which form the topmost portion of the Weald Clay and were passed through both at Brabourne and at Dover. A brick-yard close to Pluckley Station, 600 yards west of the boring, shows clays of the mottled red and yellow type at the surface; and the boring, so far as one could judge from the mashed fragments drawn from the chiselled hole, passed through much massive clay of this character in the first 250 feet, and again, at intervals, between 450 and 500 feet, in the portion of the section which we have correlated with the Weald Clay. Similar clays recurred in plenty among the Hastings Beds, between depths of 760 and 960 feet. At the outcrop in the Weald, clays of this type are more characteristic of the Hastings series—and especially of its lower sub-division, the 'Fairlight Clays'—than of the Weald Clay. They appear to denote peculiar local conditions—perhaps the existence of temporary shallow lagoons—which were established sporadically from time to time at different stages in all parts of the Wealden area. Hence they are of little value for purposes of correlation.

The laminated silty beds which we have included within the base of the Weald Clay may quite likely be equivalent to part of the sandy Hastings Beds (Tunbridge Wells Sand) of the outcrop; but, as previously remarked, it seems futile to discuss the possible correlation of subdivisions in such a locally variable series, and we have adopted the more obvious course of taking the highest thick bed of sand as the top stratum of the Hastings series.

Allowing for the upper beds not pierced by the boring, our classification gives a thickness of slightly over 800 feet to the Weald Clay at Pluckley, as against 109 feet at Brabourne, and 50 feet at Dover.

Hastings Beds.

There were many gaps in the series of cores obtained from this part of the section, so that the beds could not be studied in much detail, and the data given above depend largely upon the engineer's record, with such further information as could be obtained from the imperfect cores.

The top bed of sand appeared to be of finer texture than at Brabourne; and in no part of the series did we notice any coarse pebbly deposits like those found at Dover. If this upper sand be considered as the equivalent of the Tunbridge Wells Sand—a correlation rendered very doubtful by the uncertainty respecting the base of the Weald Clay already referred to—we should still be at a loss to find an equivalent for the Ashdown Sand which forms a well-marked lower sandy subdivision at the outcrop a few miles to the south-westward.

The strata between the depths of 880 and 960 feet corresponded fairly well in lithological characters to the Fairlight Clays of the coast-section east of Hastings; but at Pluckley we had also the base of the series revealed, and found, as at Brabourne and again at Penshurst, that the downward change to the Purbeck type of deposit was apparently gradual and without definite boundary.

The marly clays were frequently slickensided and disturbed, while the laminated shaly beds likewise occasionally showed crumpling and distortion of the bedding-planes. Sporadic disturbances of this kind are common in the Wealden beds; they do not seem to be indicative of earth-movement in the wider sense, but of local 'creep' set up during the consolidation of the beds, by differential shrinkage and by concretionary action. They were especially conspicuous in the gypsiferous portion of the Purbecks, both in this section and at Penshurst. When the cores of hard clay and shale had been partly worn away by the current of water in the boring-tube, a nodular structure was frequently brought out, showing a slight concretionary hardening of the clay in knots that were imperceptible on a fractured surface. The splendid cone-in-cone structure displayed by some of the hard claystone bands, along with the prevalence of septarian structure in them, was further evidence of the agency of concretionary forces.

Very few fossils were obtained from the series, only partly to be explained by the imperfection of the cores. We found a few good plant-remains at a depth of a little below 800 feet, preserved in shaly sandy clay; and layers of cyprids occurred at intervals, becoming more frequent in the lower portion of the series; but no shells were noticed in the material from the Hastings Beds until a depth of 956 feet was reached, only about 35 feet above the base adopted for the division: (for further palæontological notes, *see* Chap. XI., p. 179). As there was a similar scantiness of molluscan remains in the Hastings Beds both at Brabourne and at Dover, in spite of the more adequate opportunities there afforded for the investigation, we may conclude with some confidence that the conditions in the eastern part of the district during the deposition of the series were unfavourable to the existence—or, at any rate, to the preservation—of the freshwater mollusca which thrived in such abundance during some stages of the same period in the area to the westward, as exemplified in the Penshurst section (*see* p. 71). The shallows at the north-eastern side of the Wealden lake or estuary, with their shifting banks of fresh sediment, were probably less fitted for these organisms than were the deeper and clearer waters of the central basin.

At Pluckley, the expansion of the Hastings Beds, equally with that of the Weald Clay, shows that in our progress westward we are passing steadily further within this Wealden basin, for the former series has a thickness of 310 feet, as compared with 200 feet at Brabourne and 35 feet at Dover.

Purbeck Beds.

Adopting, as at Brabourne, a conventional line for the boundary between the Hastings Beds and the Purbecks, we have taken as the topmost portion of the latter division, some dark green shaly clays, setting in at a depth of 990 feet, which were unsatisfactorily represented in the cores. The first bed to show definitely Purbeckian characters was reached at a depth of a little over 1,000 feet, where the boring passed through a clayey or loamy breccia, similar in structure to the peculiar material at Brabourne already described, though somewhat different in composition and finer in texture. Unfortunately here, again, the cores were scanty, so that the whole of the bed was not seen, and its thickness could be only approximately ascertained; but we have no hesitation in correlating the stratum with that of the Brabourne section. From its character, we may be fairly certain that the level of the deposit at the time of its accumulation was practically the same at both places, so that it supplies us with another useful horizon for calculating the progressive earth-movements in the region (*see* p. 92). It may be here noted that in the Penshurst section we did not find any bed of this peculiar type, though the underlying flaggy calcareous claystones were very fully represented there.

Alternations of hard claystone or marlstone, argillaceous limestone, and concretionary cement-stone with partings of dark shale, generally showing the same flaggy or laminated structure and compact splintery fracture as at Brabourne, were predominant at Pluckley for 50 feet below the above-mentioned breccia. These need no further description than they have received in the foregoing account of the Brabourne section. The group is, however, expanded at Pluckley, so that the Purbecks attain a thickness of 101 feet, as compared with their 68 feet at Brabourne; and this increase is accompanied by a plentiful development of gypsum in the lowermost 30 feet of the division. At Brabourne the mineral was present only in a few thread-like veins, but at Pluckley it formed conspicuous bands, both along and across the bedding, besides being intimately mingled in places with the cement-stone rock-bands. In the Penshurst section, where the Purbecks were swollen in thickness to between 500 and 600 feet, gypsum occurred in still greater quantity throughout the lower 120 feet of the series.

There were no cores at Pluckley to show the actual base of the Purbecks; but at Penshurst, where this horizon was clearly shown, the junction with the underlying marine Portlandian strata was sharp, being indicated by a sudden change of lithological type. Probably the same was the case also at Pluckley, though in this section the Purbecks appeared to become rather more sandy toward the base.

For reasons already stated, our collections from the Purbecks of Pluckley have yielded very scanty palæontological results; they are given in Chap. XI., p. 179.

The Portland and Kimmeridge Section.

Portland and Kimmeridge at Pluckley.

		Thickness. Feet.	Depth from surface. Feet.
	Purbeck Beds: *see* p. 60: to ... (junction not shown in the cores)	...	... 1,091
Portland Beds, 70 ft.	Greyish-yellow muddy sandstone, with fossiliferous calcareous bands, and about 5 ft. sandy limestone or calcareous sandstone at base: strong bituminous odour generally prevalent: fossils chiefly casts of large lamellibranchs,—*Trigonia*, *Pecten*, &c.. cores represent rather less than one-half the thickness	64	
	Greyish muddy sandstone as above, with clayey streaks toward base	6	... 1,161
	apparently passing down gradually into—		
Kimmeridge Clay, 526 ft. +	Dark shaly fossiliferous clay, with occasional bands of hard calcareous claystone: cores somewhat imperfect ...	79	... 1,240
	Harder smooth dark shale with bands of brown claystone: good cores, except toward base	160	... 1,400
	Rather sandy shale and clay with hard bands of fossiliferous muddy calcareous sandstone: much core lost in the more sandy beds	115	
	Pyritous sandy clay, slightly micaceous, passing down into less sandy dark grey shale with a few fossils: fairly good cores, but diameter only 2 ins.	44	
	Thick bands of dark greyish hard calcareous fossiliferous sandstone, more or less glauconitic and muddy; alternating with beds and partings of clay or shale: containing *Astarte*, *Exogyra*, *Lingula*, &c., and crushed ammonites: fairly good cores...	49	
	Dark grey clay or shale: *Exogyra*, &c.: good cores	36	
	Muddy calcareous glauconitic sandstone...	4	
	Dark grey clay or shale	16	
	Greenish glauconitic sandstone: thickness uncertain as only part of core was obtained	about 15	... 1,679
	Fine-grained bluish-grey limestone: only a fragment of core drawn	about 8	
	Bottom of boring at	...	... 1,687

Portland Beds.

The Portland rocks at Pluckley so closely resemble their equivalents at Brabourne and at Penshurst, where they were seen to better advantage, that the section given above needs little additional comment. Casts of marine fossils, including *Trigonia* and a large *Pecten* (*see* p. 180 for further details), occurred in a dirty yellowish sandstone immediately below the base of the Purbecks, at a depth of 1,091 to 1,092 feet, showing how abruptly the conditions had changed. There did not appear to be any development of sandy limestone at the top of the division, such

as occurred at Brabourne, but some calcareous bands were present at lower levels, which might however be only of a concretionary character.

If the cores that were obtained were fairly representative of the whole sequence, it consisted here essentially of a soft loamy or muddy sand-rock, with occasional fossiliferous bands indurated by lime, and it passed down gradually into the Kimmeridge Clay. This downward passage into the underlying clays was also evident at Penshurst; but at Brabourne, as previously described, the Portlandian base was marked by a lithological break. In the last-mentioned section, however, the series had a thickness of only 31 feet, as compared with 70 feet at Pluckley, and with 131 feet at Penshurst.

Kimmeridge Clay.

The gradual transition from the Portland sandstone to the Kimmeridge Clay at Pluckley made it certain that the highest portion of the Kimmeridgian series was present here, while at Brabourne, as we have seen, this portion was missing. Unfortunately, the small diameter of the cores (2 to $2\frac{1}{2}$ inches only) and the scarcity of fossils at Pluckley gave limited opportunity for a palæontological comparison of the upper part of the two sections, which agreed in showing dark shaly clay at the top with some paler bands of marly and sandy clay below, containing layers or concretions of brownish claystone. On palæontological evidence, discussed in Chap. XI., p. 180, it appears probable that the topmost 79 feet of the Pluckley Kimmeridge section is altogether unrepresented at Brabourne, and that the next 110 feet at Pluckley is equivalent to the top 64 feet at Brabourne, so that the Upper Kimmeridge Clay is, in all, 125 feet thicker at Pluckley. We are here entering the deeper basin of the Kimmeridgian sea, though not yet within the area of maximum sedimentation, as it will be shown that equivalent sediments were very much thicker at Penshurst (pp. 188-91).

The Lower Kimmeridge Clay or Virgula Beds at Pluckley consisted of rather sandy clays and calcareous sandy rock-bands sometimes rich in glauconite, representing the similar glauconitic sandy beds of the Brabourne section and the sandy loams of Dover. Their characters indicate that the area was not quite beyond the reach of the off-shore currents. They had been proved to a thickness of 340 feet when the boring was stopped, whereas the full series at Brabourne was only 198 feet thick. The lowest bed reached was a limestone differing somewhat from any of the overlying glauconitic calcareous sandstones, but not of the Corallian type; whether this was simply a band in Kimmeridge Clay, or was an indication of the base of the series remains uncertain, as only a small portion of the lowest core was recovered; but the palæontological evidence, so far as it goes, suggests that the boring did not reach the base of the formation (*see* p. 181). At any rate, the fossils from the beds above the lowest limestone were all of Kimmeridgian character.

The palæontological lists and descriptions will be found in Chap. XI., pp. 180-2.

CHAPTER V.

THE PENSHURST SECTION.

General Notes.—The most westerly of the sections dealt with in this memoir is that of the deep boring sunk to a depth of 1,867 feet in the valley of the Medway River, 3 miles above (=SW. of) Tonbridge. Its position is 23¼ miles distant W5°N. from the Pluckley section, and about 45 miles from the Dover shafts.

The site of the boring is on the right (SE.) margin of the alluvial flat of the Medway, 1½ miles NE. of the village of Penshurst and ¼ mile NW. of the farmstead of Ensfield, at an elevation of about 85 feet above Ordnance Datum. It is located on the faulted crest of a subsidiary anticline in the Wealden Series, which brings the Ashdown Sand, one of the lower divisions of the Hastings Beds, to the surface. The outcrop of the Weald Clay, here narrowed to a breadth of 4 miles, lies to the north of it; and the boring began in beds which are nearly 1,000 feet lower in the Wealden sequence than those which formed the outcrop at Pluckley. Nevertheless, the relative thickening of the remaining Wealden and of the Purbeck sediments proved to be so great that all this initial advantage was lost by the time that the Portlandian strata were reached; and the boring was abandoned while still in the Kimmeridge Clay at a higher stratigraphical horizon than that attained at Pluckley.

The work was begun in the summer of 1897 and continued until the spring of 1899. The cores were more adequate than in either of the two foregoing sections, their production being started at a depth of 28 feet and being continued downward to the bottom, with a diameter at first of 6½ inches, contracting by stages to 2 inches at the lowest levels. They were for the most part clean-cut and nearly continuous, affording excellent opportunity for the investigation of the strata.

We were at first allowed access to the boring while the work was in progress, and our information regarding the strata down to the depth of 997 feet was obtained under these conditions. But the permission was then withdrawn until after the boring was finished, when we were granted the privilege of examining and collecting from the cores during the dismantling of the apparatus. By that time, however, some of the more perishable clayey sediments had become partly disintegrated, and there was also difficulty in reaching the earlier tiers of cores beneath a low flooring, so that our information is not so full as it might otherwise have been, particularly for the portion of the section between the depths of 997 and 1,031 feet. Nevertheless, the results on the whole were satisfactory, and were of peculiar interest for comparison with the sections previously described.

A summarised account of the boring has been published by Prof. W. Boyd Dawkins in the Report of the Royal Commission on Coal Supplies (pt. x., 1905, p. 30). Full details of the section,

including reference to some of the fossils, have also been contributed by Prof. Dawkins to the Survey memoir, "The Water Supply of Kent" (pp. 231-4).

Except in some points of minor detail, the classification adopted in the following record of our own observations is the same as that contained in the above-mentioned publications. The results of the boring are shown in abstract in Fig. 5, p. 68.

In more fully describing the section we shall follow the same method as with the Pluckley boring, dealing first with the unbroken sequence of Wealden and Purbeckian strata, and afterwards with the similar sequence of Portlandian and Kimmeridgian deposits.

The short tabular description of the two groups is supplemented in each case by a more particular discussion of the chief points, with comments on their significance in the correlation.

One of the most valuable results of this boring is that while the sequence, so far as it goes, is approximately similar to that found in the well-known Sub-Wealden boring made over 35 years ago near Battle, in Sussex, the site of which is distant about 19 miles south-eastward from Penshurst, we are enabled, on the other hand, to correlate the strata with the proved sequence at Pluckley and at Brabourne, and thus to link up the hitherto isolated results of the Battle boring with the very different sections obtained from the recent explorations in north-east Kent.

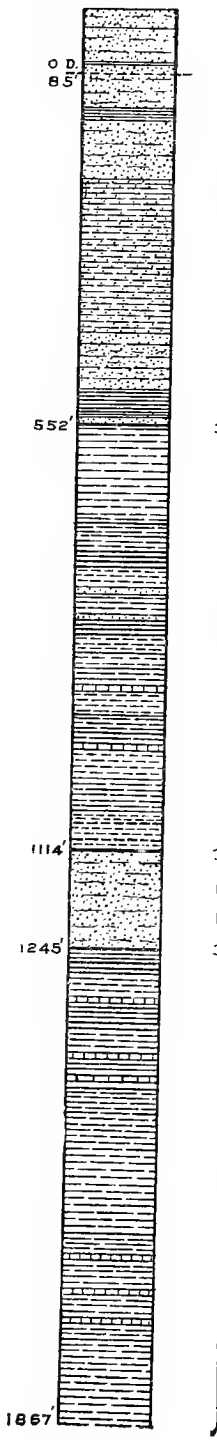
The Wealden and Purbeck Section.

Wealden and Purbeck at Penshurst.

		Thickness. Feet.	Depth from surface. Feet.
Lower portion of Hastings Beds (*cont. on p.* 69).	Superficial :—soil 1 ft. : sand and gravel 2 ft.	3	
	Pale yellowish fine-grained sand-rock or soft sandstone with bands of silty or sandy shale	22	
	Dark blue shaly clay	2	
	Yellowish soft sandstone and sandy shale as above	46	
	Mottled red and grey sandy clay ...	4	
	Yellowish soft sandstone, with shaly partings and a 1-ft. band of mottled red and grey clay	53	
	Mottled red and grey shaly clay... ...	17	
	Yellowish-grey and greenish-grey fine-grained sandstone with shaly partings	73	... 225
	Brown, dark blue, and greenish silty or sandy clay and shale	7	
	Sandy shale, predominantly pale grey and silty, but occasionally dark grey and greenish; with some bands of soft yellowish sandstone: fragmentary plant-remains abundant, and a layer of cyprids noticed at depth of 359 ft. ...	196	
	Dark blue shaly clay	4	
	Yellowish-grey and greenish shaly sandstone and sandy shale, with some well-preserved ferns near base	42	... 474

FIG. 5.—PENSHURST: SUMMARISED SECTION OF THE BORING.

Scale: 1 *inch* = 250 *feet:* (*same as Figs.* 2, 3 *and* 4).



Thickness. Feet.

Hastings Beds (incomplete at top), with soil, etc.; 552
for details, *see* pp. 67, 69.

Purbeck Beds; 562
for details, *see* pp. 69–70.

Portland Beds (sandstone); 131
for details, *see* p. 75.

Kimmeridge Clay (upper part); ... ... 622+
for details, *see* p. 75.

		Thickness. Feet.	Depth from surface. Feet.
Lower portion of Hastings Beds: say, 549 ft., base indefinite.	Dark grey silty or sandy clay and shale, with fragments of plants, fish-scales, &c.	2	
	Grey and greenish sandy shale and sandstone with bands of brownish and bluish shaly clay, and nodules of clay-ironstone: at base, a 4-in. band of hard nearly white calcareous sandstone with bits of plants	30	
	Laminated grey and blackish shaly clay and silty shale, streaked with white shelly layers and bands of clay-ironstone: alternating with thin beds of hard nodular greenish clay, often showing much broken bedding and full of slickenside-planes: fossils include *Unio*, *Cyrena*, *Viviparus*, with abundant cyprids, and fish- and plant-remains ...	39	
	Whitish sandstone, traversed by silty and carbonaceous bedding planes and becoming shaly below, with a ½-in. band of hard calcareous sandstone at base ...	7 ...	552
Purbeck Beds (*cont. overleaf*).	Alternations of thinly bedded dark silty shale; clayey shale with brown ironstone bands and nodules; greenish and grey shales with slickensides and broken bedding, containing ramose pyrites and clay-ironstone nodules; and thin bands of fine-grained hard calcareous sandstone with shale partings: a gypsum vein at depth of about 630 ft.: fossils—freshwater shells, cyprids, &c., as above	130	
	Band of hard pale-grey calcareous sandstone with large ophitic plates of crystalline calcite, giving excellent 'lustre-mottled' effect	1 ...	683
	Alternations of dark blue, brownish, black, grey and greenish laminated shale as above, with silty intercalations, pyritous and clay-ironstone bands, thin layers of impure shelly limestone and hard calcareous sandstone: in places much crumpled, slickensided, and brecciated, but general parallelism and gentle dip of bedding maintained: strong odour of bitumen in some beds: many layers crowded with fossils, chiefly *Cyrena*, cyprids, plant- and fish-fragments, with occasional *Melania ?*	119 ...	802
	Hard blackish shales and grey silty shales, with occasional intercalations of disturbed green clay much slickensided, pyritous and claystone bands, and flaggy beds of calcareous sandstone and shelly limestone: fossils abundant, including some marine or estuarine forms—*Ostrea*, *Modiola*, *Protocardia*, *Melanopsis ?* &c., with *Cyrena*, &c., as before	54	
	Smooth splintery calcareous shale or flaggy claystone, with bands of brownish nodular limestone: bedding crumpled and broken in places: very few fossils except occasional layers of cyprids, and plant- and fish-fragments ...	46 ...	902

		Thickness. Feet.	Depth from surface. Feet.
Purbeck Beds, 562 ft.	Brownish-black shale and calcareous clayey flagstones with shelly layers: *Cyrena*, *Modiola*, cyprids, &c.	3	905
	Black, brownish and pale blue splintery calcareous shales and flaggy cement-stones, with seams of brown bituminous shale and bands of hard limestone, the latter becoming predominant toward base: many thin streaks and veins of gypsum, and bedding in places much disturbed: fossils rare	86½	
	Band of grey fine-grained limestone made up principally of cyprids and comminuted shells	1½	993
	Smooth splintery hard calcareous banded shale and flaggy claystone, dark grey, bluish and greenish; with veins and layers of gypsum, and gypsiferous cement-stone bands, especially toward base: strong bituminous odour prevalent throughout: fossils apparently scanty except occasional seams of cyprids and fish-remains, but the upper 40 ft. of these beds not well seen ...	69	
	Gypsum, mixed with a little shale and cement-stone	6	1,068
	Hard gypsiferous cement-stones, with bituminous shaly bands: the gypsum occurring in bands, veins, balls and pebble-like lumps as at Netherfield: cyprids and fish-remains abundant in the shales	46	
	Gypsiferous cement-stone at base, resting with sharp junction on Portlandian shaly sandstone (*see* p. 75), at ...	...	1,114

Hastings Beds.

The geology of the ground in the neighbourhood of the boring is complicated by the presence of faults, so that it is not easy to estimate what horizon in the Ashdown Sand is represented at the surface; but as the site lies well within the outcrop of the division, as shown on the Geological Survey map (Old Series, Sheet 6), we ought probably to allow a thickness of not less than 100 feet for the portion removed by erosion at this place. So variable, however, are the subdivisions of the Hastings Beds that we must not place too much confidence on the recognition of the stratigraphy in this quarter, though the geological map shows clearly enough that we attain here a comparatively low position in the series.

Presuming, then, that the pale soft sandstone or sand-rock forming the uppermost cores may be taken to represent a portion of the Ashdown Sand, which is the lowest sand of the Hastings Beds that is shown separately on the map, we should continue this subdivision downward to a depth of at least 225 feet, and

perhaps much lower. Down to the depth just mentioned the cores consisted mainly of fine-grained sand-rock, frequently much dappled with coaly bits of plants and streaked with shale; but this part of the section also included some minor argillaceous beds, mostly of the red-mottled clay type, with at least one band of dark blue clay-shale.

Below 225 feet the composition of the deposits for the next 250 feet differed only in the reversed proportions of the sandy and clayey constituents, and in the absence of redness from the latter. The shales which predominated in this part of the section were generally more or less sandy or silty, with some alternations of stiff hard clay, often greenish in colour, and with occasional beds of fine-grained sandstone. If considered to be part of the Ashdown Sand division, its thickness in the boring may be reckoned at about 470 ft., which, with the addition of 100 ft. for the portion removed by erosion, gives a total of about 570 feet. This exceeds the greatest thickness hitherto allowed for the Ashdown Sand by more than one-third, but the local variations in the Wealden deposits are everywhere so effective that changes in thickness count for little. At the same time we may, with equal reason, regard these clayey beds as in part equivalent to the Fairlight Clays which underlie the Ashdown Sand on the East Sussex coast, though the lithological resemblance is not particularly close. For our present purpose, however, it will suffice, without further discussion of these minor possibilities of correlation, if we recognise that the Ashdown Sand of the outcrop passes down by alternations into a thick series of clays which merge gradually and without definite boundary into deposits of unmistakably Purbeckian type.

The lowest 80 feet of strata which we have included within the Hastings Beds consisted of dark laminated shales and greenish clays with nodular bands of clay-ironstone and some layers of hard calcareous sandstone. Similar bands of ironstone and sandstone recurred frequently in the underlying Purbecks. The sandstones occasionally showed a segregation of calcite among the sand-grains into obscure crystals an inch or two in diameter, giving a patchy play of light from the rock, known as 'lustre-mottling.' The bands of hard calcareous grit that occur in the lower part of the Hastings Beds near Winchelsea, and among the Purbecks of the Sussex inliers, though mostly of coarser grain and darker colour, are analogous in many respects to those of the boring. It is noteworthy, also, that a similar thin bed of calcareous sandstone showing the crystalline structure was penetrated toward the base of the Hastings Beds in the Brabourne boring.

In the sandy upper portion of the series fossils were scanty, and those obtained were principally of fragments of plants (including some good fern-leaves from the depth of 474 feet) and of fish, with an occasional layer of cyprids. The clays of the lower portion were, however, frequently crowded with fresh-water shells, forming white bands which strongly accentuated the bedding. These fossils are discussed in the palæontological portion of this memoir, Chap. XII., p. 183. The average dip of the beds was too slight to be measurable in the cores, but here and there the stratification was sharply crumpled and confused by local disturbances,

as at Pluckley and Brabourne, and slickensided surfaces were plentiful, especially in the green lumpy clays.

The Penshurst section shows greater thicknesses of Lower Wealden and Purbeck strata than have been proved at any other place within the Weald. As the sediments are all of comparatively shallow-water type, it follows that they must have been deposited upon a slowly subsiding area. That the submergence was due essentially to a movement of the land and not to an independent change of sea-level is demonstrated in this case by the fact that the whole of the Wealden and most of the Purbeck strata were deposited in fresh-water, apparently in a slowly deepening lake-basin. As will be subsequently shown, the Penshurst site probably lies near the central part of the old depression, where the accumulation of sediment reached its maximum.

It is doubtful whether the conventional base which we have adopted for the Hastings Beds in this boring will correspond exactly with the horizon selected for the base under similar indefinite conditions at Pluckley and at Brabourne. Hence the relative thickness of the Lower Wealden strata in the three sections must not be too exactly interpreted; but it will be noticed that the strata *below the top of the Ashdown Sand* at Penshurst are at least twice the thickness of the *whole* of the Hastings Beds at Pluckley, and over thrice the equivalent thickness at Brabourne.

Purbeck Beds.

The similarity of the upper 250 feet of strata classed as Purbeckian in the above section, both lithologically and palæontologically, to the 200 feet of overlying beds has been already commented on; but as a whole they were more persistently shaly, contained fossils in greater abundance, and included fewer and thinner sandstone bands. Pyritous beds and layers of clay-ironstone also became more plentiful, the latter sometimes showing a curiously wrinkled concretionary structure. The local crumpling with partial brecciation of the bedding-planes, noted in the Lower Wealden strata, was often still more strongly marked in the Purbecks, increasing in intensity downward until its maximum was reached in the gypsiferous beds forming the base of the Purbecks. This crumpling was sometimes beautifully brought out in the cores by the puckering of the shelly layers; but the general horizontality of the bedding was not affected by it.

We saw nothing in this section resembling the earthy breccia of the Brabourne and Pluckley Purbecks, and its absence supports our view that this peculiar deposit was formed only at the margin of the old basin. In its place we have here the thick clayey sediments denoting an area of steady subsidence.

In the upper 150 feet of these shaly strata the hard bands were mostly of clay-ironstone and calcareous sandstone, but below this depth the fossil mollusca became so numerous that they formed at intervals flaggy layers of shelly limestone like those which are dug at the Purbeck outcrop in Sussex. All the shells that we obtained from above the depth of 800 feet were fresh-water species,

mainly of the genera *Cyrena* and *Unio*. *Viviparus* also was abundant down to a depth of 680 feet, but was rare at the lower levels. Cyprids were abundant throughout, occasionally forming bands of calcareous rock with a pseudo-oolitic structure. Fragments of fish and plants were seldom absent, being particularly plentiful in the layers of calcareous sandstone. (For further notes on the fossils *see* pp. 184-6.)

In their fossil contents and in their lithological characters the above-described beds correspond fairly well with the Upper Purbecks of the Dorset coast-sections. The next 100 feet of strata in the downward sequence at Penshurst are characterised by the presence of brackish-water fossils, suggesting their equivalence to the Middle Purbecks of Dorset, and the lowest 200 feet of the division have many characters in common with the Lower Purbecks. The whole series, however, at Penshurst much exceeds its maximum thickness in Dorset.

No purely marine forms were found in the Purbecks at Penshurst, but estuarine or brackish-water shells of the genera *Ostrea*, *Modiola*, *Protocardia* and *Melanopsis?*, intermingled with *Cyrena* and cyprids, occurred in numerous layers between the depths of 800 and 856 feet, and were noticed again in a belt some 50 feet lower in the section. The beds containing them were dark calcareous flaggy shales which were interbedded with and passed down into compact splintery claystone flags resembling the rocks of the same horizon at Pluckley and Brabourne, but of much greater thickness. As in the former sections, these claystones contained very few fossils, were strongly impregnated with bitumen, and were streaked with partings of black or brown bituminous shale. The estuarine species ranged discontinuously through these strata for a little over 100 feet, and we failed to find them in the underlying portion of the division.

Judging from their relative stratigraphical position, it is probable that the similar brackish-water fossils found in a few places at the outcrop of the Purbecks in Sussex[1] and in the boring at Heathfield railway station[2] occur at approximately the same horizon in the series as at Penshurst. We have already seen that traces of the same conditions were shown by the Purbeck fossils of Brabourne (*see* p. 40). Thus we have evidence of a far-reaching incursion of salt-water in the Wealden area at about the period when the marine influence was most strongly marked in the Dorset sequence. As this horizon in the Weald clearly marks the marginal level of the ancient sea, we have here another

[1] "Geology of the Weald," p. 42; and "Jurassic Rocks of Britain," vol. v., pp. 282–5, *Mems. Geol. Surv.*

[2] C. Dawson, "On the Discovery of Natural Gas in East Sussex," *Quart. Journ. Geol. Soc.*, vol. liv. (1898), pp. 567–71.

Mr. Dawson suggests that the top of the brackish-water shell-beds should be taken as the upper boundary of the Purbecks in the Weald. The Brabourne and Pluckley borings show, however, that there are beds of unmistakably Purbeckian type above this horizon. But Mr. Dawson, in common with all other workers in the same field, fully recognises that any line of division between the Hastings Beds and the Purbecks must necessarily be arbitrary and conventional (*op. cit.*, p. 567).

useful datum-line from which, by reference to the lower and higher horizons of the same kind, to measure the earth-movement of the intervening periods (*see* Chap. VII.).

The lowest 200 feet of the Penshurst Purbecks consisted principally of calcareous and bituminous shales, compact splintery claystone flags, and thicker beds of marly cement-stone, with occasional bands of purer limestone speckled with cyprids. Below the depth of 900 feet this series was streaked at intervals with thin veins of gypsum; below 1,050 feet the gypsum increased in quantity and formed massive veins and bands which continued to be prevalent down to the bottom of the series at 1,114 feet. The strong disturbance of the bedding in these richly gypsiferous strata has already been mentioned; it was comparatively slight in the underlying Portland rocks, and was hardly ever seen in the Kimmeridgian; which bears out our suggestion that it has been brought about mainly by shrinkage and other local changes during the consolidation of the beds and the segregation of their constituents.

The gypsiferous beds proved in the Sub-Wealden boring and now mined on an extensive scale at Netherfield, are similar in all respects to those above described, except that their thickness is only about 60 feet. At Pluckley, also, the lowest part of the Purbeck series was rich in gypsum, and at Brabourne the mineral occurred, though scantily, at the same horizon.

Similar conditions prevail in the Lower Purbecks of Dorset, where again gypsum is sufficiently abundant to have been commercially worked. So once more we have evidence for identical conditions ruling contemporaneously over the greater portion of the Purbeck basin; and if, as is supposed, the gypsum has been concentrated in drying lagoons close to sea-level, we may postulate that there was more rapid subsidence in progress at Penshurst during the Lower Purbeck stage than at Netherfield or at Pluckley.

In the Penshurst gypsiferous beds, as is usual, fossils were rare; they consisted almost entirely of cyprids and fragments of fish. The shales associated with the gypsum were often bituminous, and all the beds smelt strongly of petroleum.

The total thickness of the Purbeckian series in this section, according to our classification, is about 560 feet, which is greater than their proved maximum in any other English district. At their thickest in Dorset they reach about 400 feet; in the Sussex exposures and borings they are also estimated to attain 400 feet; in the Pluckley boring, as we have seen, they were just over 100 feet thick, and at Brabourne under 70 feet. But in spite of this extreme augmentation there is no indication in the Penshurst deposits that they were accumulated rapidly. Indeed, the thinly laminated structure of the major portion and the presence of multitudinous layers of large well-grown shells would lead us *a priori* to the opposite conclusion. The gypsum beds also, and the many bands of concretionary ironstone, claystone, and limestone all imply slow sedimentation. Hence, we must infer that a long period of time was consumed in the accumulation of the series.

The Portland and Kimmeridge Section.

Portland and Kimmeridge at Penshurst.

		Thickness. Feet.	Depth from surface. Feet.
	Gypsiferous Purbeck Beds, as above, to resting sharply on—	...	1,114
Portland Beds, 131 ft.	Dark grey calcareous sandstone, shaly in the upper 2 ft. and more massive below; containing many ill-preserved crushed fossils, representing a marine fauna up to the top, including "*Holcostephanus*," *Trigonia*, *Pecten lamellosus*, *Ostrea*, *Perna*, *Serpula*, &c.: passing down into—	6	
	Massive soft greenish-grey muddy fine-grained sandstone, making long unbroken cores: containing obscure blackish casts of shells in places: "*Holcostephanus*," *Trigonia*, *Pecten*, *Ostrea*, *Serpula*, &c.	60	
	Darker sandstone, mixed with dingy carbonaceous matter and clay; passing down by alternations into harder dark calcareous rocky sandstone and sandy shale with wisps of clay: the hard rock containing abundant and better preserved fossils, of last-mentioned genera	59	
	Dark grey sandy calcareous shale with a few obscure fossils: chiefly *Ostrea*, *Pecten*, &c.: passing down gradually into dark blue clay of Kimmeridge type...	6	... 1,245
Kimmeridge Clay, 622 ft. +	Dark blue clay, with marly conchoidal fracture, interbedded with hard nodular calcareous claystone bands: fossils of upper part include species of "*Holcostephanus*"; *Lingula ovalis*, *Modiola autissiodorensis*, *Pinna*, &c.	17	
	Dark blue and paler grey clays, slightly shaly in places but mostly with massive marly structure: bands of calcareous claystone at intervals, but more rarely in lower part: fossils fairly abundant, but of few species: *Perisphinctes*, *Lingula ovalis*, *Trigonia*, *Pecten*, &c. (*see* list p. 192)	168	
	Dark blue and blackish clays, more shaly than above, and in places pyritous: with bands of harder clay, but only one layer of calcareous rock seen, (at 1,486 ft. depth): *Orbiculoidea latissima*, *Modiola autissiodorensis*, *Protocardia morinica*, &c. ...	190	... 1,620
	Hard clays with thick beds of smooth pale brown and dark grey calcareous cementstones and some thin bands of brown bituminous shale (inflammable): fossils scanty	140	
	Dark blue shaly clays, with brown bituminous shales at intervals, but few or no cementstones: fossils, not abundant, include *Perisphinctes*: *Astarte* (several species), *Lucina minuscula*, &c.	107	
	Bottom of boring at	...	1,867

Portland Beds.

In composition the Portlandian strata at Penshurst closely resembled their equivalents at Pluckley and Brabourne, but were

increased in thickness to 130 feet as compared with 70 feet and 30 feet respectively in the two previous sections. The sandstone, which was the main constituent, was of the same soft loamy type and dingy greenish colour, and contained fossils, chiefly in the state of casts, of the same kind and in the same condition as at the other places.

The gypsiferous marlstone forming the base of the Purbecks rested with a sharp line of demarcation upon shaly calcareous sandstone, full of marine fossils, which was the topmost bed of the Portlandian. There was however no sign of erosion or unconformity at the junction, but only a sudden change in the type of sediment; the bedding, except where crumpled, remained as nearly flat as in the overlying beds. For the first 6 feet the rock was full of fossils, and contained sufficient calcareous matter almost to deserve the designation of sandy limestone. Below this for the next 60 feet it was much less limy and yielded comparatively few fossils, being a massive homogeneous rock with the bedding planes very feebly developed. From the excellent cores representing this part of the section we selected the unbroken specimen 10 feet in length which is now exhibited in the Museum of Practical Geology (Main Gallery), Jermyn Street, London.

At lower depths the bedding became more pronounced again, being often accentuated by clayey streaks; and the sandstone also, as at Pluckley, included hard calcareous bands containing many fossils. These beds merged gradually downward into sandy shale, which formed an unbroken passage into the Kimmeridge Clay.

Owing to the poor condition of the fossils our list is meagre, but, taken in conjunction with that from the same beds at Brabourne, the forms are sufficiently characteristic to enable us to refer the strata to the stage of the Portland Stone of Dorset (*see* Chap. XII., p. 188).

Kimmeridge Clay.

Respecting the lower 620 feet of the boring there is not much information to record beyond that which has been given in the above section. It is noteworthy that the upper portion of the Kimmeridge Clay did not possess the shaly laminated bituminous character which is usually found in the British Upper Kimmeridge beds, but was composed of softer clay, for the most part not very distinctly bedded and with a prevalent marly or dicey fracture. The palæontological evidence, discussed in a later chapter (Chap. XII., pp. 188-97), shows that the upper part of these beds has its equivalent in the Portland Sands of Dorset; but it is impossible in Kent to draw any stratigraphical line among these upper clays, as all the sediments are lithologically of the Kimmeridge Clay type. These clays continued downward without much change of lithological type for 375 feet, and it was only below this that we noticed the presence of bituminous shales, which then recurred at intervals, in comparatively thin bands, down to the bottom of the section. The Sub-Wealden boring seems also to have penetrated deeply into the formation before bituminous shales were reached[1].

[1] "The Jurassic Rocks of Britain," vol. v., *Mem. Geol. Surv.*, 1895, p. 346.

The absence of the sandy type of deposit in the Kimmeridge at Penshurst has already been commented on, and the palæontological evidence shows that the Lower Kimmeridge or Virgula Beds which possessed these characters at Pluckley and Brabourne were not reached at Penshurst. So great is the thickening of the Kimmeridgian westward that the whole 622 feet of clays proved at Penshurst represent only the expansion of the upper clayey part of the formation at Pluckley and Brabourne. This conclusion is borne out by a boring recently made near Battle, in Sussex, the cores of which we examined in 1909, where the Kimmeridge Clay was proved to a thickness of over 1,100 feet, and contained much impure sandstone in the lower half which represented the Virgula Beds[1]. It will be remembered that the Kimmeridge Clay of the Sub-Wealden boring is stated to have a thickness of close upon 1,300 feet, and to include a considerable amount of sandstone and sandy shale in the middle portion[2]. Taking all the evidence into consideration, it therefore seems probable that at Penshurst not more than one-half of the total thickness of the Kimmeridgian formation was penetrated.

The westerly expansion actually proved by the boring is sufficiently remarkable, and when the probable thickness of the unproved portion of the formation is added, the factor becomes of great practical consequence. It is, indeed, upon the thickness of the Kimmeridgian beds at any particular spot, more than upon any other factor, that the success or failure of attempts to reach the Palæozoic floor in the south-east of England depends; for where the formation is fully developed its big addition to the sum of the other Secondary rocks will cause the undertaking to become too costly for commercial prospects.

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[1] A short account of this boring is given in "Summary of Progress of the Geological Survey for 1910," *Mem. Geol. Surv.*, 1911, p. 63.

[2] "The Jurassic Rocks, etc." *op. supra cit.*, p. 346.

CHAPTER VI.

STRATIGRAPHICAL SUMMARY.

In the foregoing chapters the stratigraphy of the four sections has been separately described; in the present chapter we propose to give a brief review of the results as a whole, dealing with the formations in ascending order. Some general deductions and considerations arising from the evidence will be left over for discussion in another chapter.

Palæozoic Rocks.

Strata of pre-Mesozoic age were reached in the two easternmost sections only. At Dover they were entered at a depth of 1,110 feet[1] below Ordnance Datum and consisted of Coal Measures, which have been fully described by previous observers and are not dealt with in this memoir.

At Brabourne the Palæozoic floor lay at a depth of 1,620 feet below Ordnance Datum. It was composed of rocks that were certainly older than Coal Measures, though their age has not been exactly ascertained. They consisted of steeply dipping and slightly cleaved marine sediments of the silty-mudstone type, and may be Devonian or older.

Triassic Rocks.

The Trias was found at Brabourne only, where it had a thickness of about 80 feet. It was absent at Dover and at other places (Ropersole, Ellinge, Fredville, and Waldershare) in East Kent where borings of which accounts have been published[2] have reached the Coal Measures. The Brabourne occurrence may indicate the margin of a basin of these deposits, extending and thickening southward. It consisted of a pebbly conglomerate made up of rolled fragments of various limestones, chert, quartzite, sandstone, &c., passing up into red and mottled marls. No equivalent of the Rhætic was seen.

Lias.

The Lias was passed through at Brabourne and at Dover. Its presence has also been recorded, but as yet without description, in the other Kentish borings mentioned in the last paragraph. Its thickness at Brabourne was 140 feet, and at Dover 38 feet, while the records of the other sections give thicknesses ranging from 5 feet[3] (Waldershare) to 54 feet[4] (Ellinge). The Brabourne section therefore showed the thickest known development of this formation in Kent.

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[1] The figures throughout this chapter are given, wherever possible, in round numbers: the units are meaningless in borings at depths where they are likely to be nullified at any time by a slight divergence from the perpendicular, or by observational error.

[2] *See* references on pp. .

[3] W. Boyd Dawkins, *Journ. Soc. Arts*, vol. lv., 1907, pp. 456–7.

[4] W. Boyd Dawkins, *Final Rep. Roy. Comm. Coal Supplies*, 1905, pt. x., p. 30

Our palæontological evidence proves that the three main divisions of the Lias were all represented at Brabourne; the Upper Lias, by smooth blue shales of the usual type; the Middle Lias, by ferruginous limestones, sandy limestones, and micaceous shales; and the Lower Lias, by marly clays and sandy shale, with calcareous and ferruginous rock-bands at the base. The evidence from Dover was more meagre, but suffices to show that the three divisions are present there also, with similar lithological characters, though each is of reduced thickness.

There was a sharp lithological break at the top of the formation in both sections, with indications of erosion at Dover. Similarly, the base appears not to be complete in either place, and the earliest zones of the formation have not been found.

Inferior Oolite and Great Oolite.

With respect to the Middle and Lower Oolites we have evidence only from the Brabourne and Dover sections. They differ greatly in detail, owing to the eastward thinning and change of lithological type. In most parts the Dover sequence finds its nearest equivalent in the rocks of the same age across the Channel in Bas Boulonnais, while the Brabourne sequence corresponds more nearly to that of the west of England.

At Dover the lowest bed of the Oolitic series was an incoherent quartzose sand, devoid of fossils, which was overlain by calcareous sand speckled with lignite, having together a thickness of some 30 feet. These beds passed up into sandy limestones containing Great Oolite fossils, with purer limestones of the same series above, the thickness of the whole limestone group being 70 feet.

At Brabourne the sandy phase was absent; and immediately above the Lias there came a somewhat impure oolitic limestone, 44 feet thick, without determinative fossils but probably belonging to the Inferior Oolite division. This was overlain by 23 feet of calcareous shale with layers of limestone, in which again the palæontological evidence was imperfect, but which corresponds fairly well with some phases of the variable Fuller's Earth series of the West of England. Then came the Great Oolite limestones, with a few characteristic fossils, slightly sandy in places and undoubtedly equivalent to the sandy limestones of Dover, though much thicker (114 feet).

The change in the sediments from the shallow- or disturbed-water type at Dover to the deeper- or quieter-water type at Brabourne becomes conspicuous for the first time at this horizon, and is repeated again and again in the subsequent formations.

Forest Marble and Cornbrash.

These members of the Lower Oolite appeared both to be represented at Dover; the Forest Marble by 18 feet of pale-green and bluish calcareous claystone, marly clay, and limestone, in places containing much lignite; and the Cornbrash by 13 feet of calcareous sandy clay. In sequence and composition, the likeness of these beds to their equivalents exposed in the new railway cuttings

of the Great Western Railway at Blackthorn Hill, Oxfordshire, which have been examined by our colleague, Mr. G. Barrow[1], is remarkably close and implies an identity in the conditions of accumulation. These strata represent the sediments of a shallow sea at a slight distance from the shore.

At Brabourne the subdivisions were less easy to distinguish, owing, perhaps, to the scanty information obtainable from a boring in respect to beds of slight thickness and variable composition. We have assigned 13 feet of greenish shale, impure limestone, and pale calcareous sandstone to the Forest Marble, but have failed separately to recognize the Cornbrash. These strata along with the overlying Kellaways Rock at Brabourne are together less in thickness than at Dover, being in this respect exceptional.

Kellaways Rock.

At Dover a series of dingy greenish loamy sands, with concretionary calcareous and ferruginous rock-bands, and a little clay, slightly over 30 feet thick, was clearly referable to the Kellaways Rock, both on lithological and palæontological evidence.

Its equivalent at Brabourne was of similar composition but more thoroughly indurated. In thickness it attained only one-half that which it possessed at Dover.

Oxford Clay and Lower Corallian Clays.

The clayey strata which lie between the sandy Kellaways Rock and the Corallian limestones have a total thickness of 176 feet at Dover and of 220 feet at Brabourne, but this includes an upper portion which is recognizably of Lower Corallian age. Stratigraphically the sequence is unbroken, but on palæontological grounds we may fix the thickness of the Oxford Clay proper to be about 88 feet at Dover and 173 feet at Brabourne.

At the last-mentioned locality the Oxford Clay consisted of bluish marly clay with very little lithological variation; while at Dover the series was more variable, being banded in places with silty, glauconitic and calcareous beds. Among the Lower Corallian clays of both sections there was a marked development of 'iron-shot' or ferruginous oolitic grains in some of the bands, and of layers of argillaceous limestone or claystone.

Characteristic fossils were obtained from both sections and the usual zonal sequence could be distinguished in those from the Oxford Clay.

The differences in the composition of the beds show that the physical conditions of the two localities maintained the same relationship as during the preceding and subsequent stages.

At the same time it is evident that the relative changes of level in the region were slighter during the accumulation of the Middle Oolites than during the periods of the Lower and Upper Oolites (*see* Chap. VII.).

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[1] "Summary of Progress for 1907," *Mem. Geol. Surv.*, 1898, p. 145.

Our information regarding the Oxfordian strata pierced in other Kentish borings and reached in the Sussex Sub-Wealden boring is at present too scanty to enable us to discuss the wider correlation.

Corallian Limestones.

The main Corallian episode was fully represented at Brabourne and Dover by corallian limestones which were very similar in composition and fossil contents, and of nearly the same thickness (approximately 130 feet), in both sections. This similarity indicates that there was probably no difference between the levels at which the series was accumulated at the two places. How far westward into the Weald the limestone reefs extended we have no evidence to show, as neither of the two westerly sections reached down to this horizon. It is noteworthy in this connexion that the Sub-Wealden boring, so far as we can judge from the confusing records of it, found no rocks of the Corallian Limestone type, the Corallian formation being represented therein by "calcareous sand with quartz pebbles, and limestone; calcareous shale and cement stone; dark shale; oolitic limestone; and sandy shale."[1]

The 'raggy' limestones were probably formed as fringing reefs to the old coast-line, at no great distance from the shore, in areas sheltered from any large amount of clayey sediment. The rubbly beds at the top of the series at Dover denote the agency either of waves or of strong currents in shallow water.

Upper Corallian and Kimmeridge Clay.

Above the Corallian limestones we reach stages in which the differences between our sections become acute. For convenience we will group together in this summary all the beds between the Corallian limestones and the Portlandian sandstone, as they form a sequence in which clays predominate, though the lower portion of it at Dover and Brabourne reaches well below the base of the Kimmeridgian, and the upper portion is probably equivalent to the Portland Sands of Dorset.

At Dover the lower beds, which must be classed as Upper Corallian, consisted of a very variable series, nearly 100 feet thick, of which the lowest 30 to 40 feet was mostly clay; but above this, the clayey basis was mixed in varying and sometimes preponderant degrees with ferruginous, glauconitic, sandy, and calcareous ingredients. The ferruginous matter occurred chiefly in brightly polished brown oolitic particles, which in the middle portion of the series were so thickly clustered as to constitute a useful bed of iron-ore, 16 feet thick, but were elsewhere more sparingly disseminated. Some of the limestone bands also had the oolitic structure; and seams of curious pisolitic rubble, composed of irregularly discoidal pellets of calcareous matter and clay, were prevalent above and below the iron-ore. The fossils of

[1] H. B. Woodward, "The Jurassic Rocks of Britain," vol. v., p. 347.

this series were ill-preserved and not particularly distinctive, but the lithological characters were like those of the Upper Corallian rocks of Wiltshire.

The higher beds at Dover, only 44 feet thick, contained a Kimmeridgian fauna, but differed lithologically from the usual type of Kimmeridge Clay, being in part composed of clayey greensand full of grit-grains, with a comparatively sparing development of normal clay. It is proved by the fossils that these beds represent only the lowest portion of the Kimmeridge Clay, which is all that has been preserved of the formation at this place.

At Brabourne the Upper Corallian had a similar development, except that the iron-ore was reduced to a few feet, while thick beds of clay and marlstone were intercalated among the more heterogeneous deposits, swelling the thickness of the series to 160 feet.

The Kimmeridge Clay was likewise greatly expanded, both in its glauconitic sandy portion and in the beds of unmixed clay, so that it attained a thickness of 260 feet. The upper 120 feet or so of this mass, however, represents a portion of the formation that is missing at Dover.

At Pluckley the Kimmeridge Clay was penetrated for 526 feet without the base being reached. The upper 250 feet was almost entirely clay, probably unrepresented at Dover and incompletely represented at Brabourne; but below this there were many intercalations of glauconitic calcareous sandstone, and this portion evidently corresponded, in a greatly expanded form, with the glauconitic beds of the previous sections.

At Penshurst 620 feet of Kimmeridge Clay was pierced, but again without reaching the base. The whole of this thickness was made up of sediments of the clayey type, a rather massive marly structure predominating in the upper 375 feet, with some laminated bituminous shales at the lower levels, and bands of calcareous claystone at intervals throughout. The fossils prove that the whole mass represents the Upper Kimmeridge alone, here attaining probably its maximum degree of expansion. The Lower Kimmeridge or Virgula Beds of the previous sections were not reached, and the absence of glauconitic sandy beds is thus to be explained.

In the old Sub-Wealden boring, the total thickness of the Kimmeridge Clay, according to the latest estimate, was 1,273 feet, the upper 700 feet being composed of clays and shales, and the remainder, of shale containing some thick intercalations of sandstone and limestone[1]. This result has been confirmed by another boring near Battle, which we have lately examined, where a similar sequence was proved in the Kimmeridge Clay through a thickness of over 1,100 feet (see *ante* p. 77).

The tilting of the Wealden region, due to the uplift of the land on the north-east and the sinking of the basin on the south-west, which was the ruling factor in its structure from the beginning

[1] "The Jurassic Rocks, &c." *op. cit.*

of the Mesozoic era, appears to have been accelerated during the Kimmeridgian period, but became retarded again in Portlandian times.

Portland Beds.

At Dover the Portlandian stage was not represented. We cannot prove whether its absence is due to non-deposition or to its removal by early Wealden erosion, but the latter supposition is very probable.

At Brabourne, Pluckley, and Penshurst the formation was well in evidence, with considerable variation in thickness, but with an essential similarity of lithological character. The chief constituent of the series in each of the three sections was a soft dingy greenish- or yellowish- grey muddy sandstone, more or less bituminous, containing casts of marine fossils, and including some calcareous bands which in places passed over into sandy limestone. This deposit is shown by the palæontological evidence to be equivalent to the Portland Stone of Dorset.

At Brabourne, where the series had a thickness of only some 30 feet, the lowest bed was a calcareous rock-band which rested with a sharp junction on the Kimmeridge Clay; but at Penshurst, and probably also at Pluckley, there was a gradual transition from the sandy Portlandian to the underlying clayey beds which are lithologically inseparable in Kent from the Kimmeridge Clay, but which, as previously mentioned, are probably equivalent to the Portland Sands of Dorset. At Brabourne there was likewise a more pronounced limestone-band at the top of the formation than was present in the other sections. The junction with the overlying Purbecks appeared to be sharp in all three places, though owing to imperfect cores it came under actual observation at Penshurst only.

At Pluckley the thickness of the series was 70 feet, and at Penshurst, 130 feet. In both places the dingy sandstone contained occasional calcareous bands and an increasing admixture of clay toward the base.

In the Sub-Wealden boring, the Portlandian appears to have been represented by deposits of a similar sandy type, reaching 115 feet in thickness. The records, however, mention the presence of chert in the upper part of the series; this substance was not seen by us in the sections now described; nor did we find it in the recent boring near Battle, where the Portlandian, about 140 feet thick, was like that of Penshurst.

Purbeck Beds.

The range of the Purbecks was the same as that of the Portlandian: they were wanting at Dover, and present in the other three sections, thickening rapidly westward. In each case they passed up insensibly into the Wealden Series, so that a conventional boundary only was attainable for their upper limit.

At Penshurst, where they reached their fullest development, we have recognized a thickness of 560 feet for the Purbeckian group. The lowest 120 feet consisted of marly cement-stones,

compact flaggy calcareous claystones and shales, sometimes bituminous; with much gypsum, in thick bands and lumps as well as in irregular veins: the scanty fossils of this group consisted principally of layers of cyprids and scattered fish-remains.

Next in the upward succession came a group of dark hard shales and splintery claystone flags, about 100 feet thick, with occasional thin bands of limestone and, in the upper part, of calcareous sandstone. This group was often exceedingly fossiliferous, the shells being chiefly *Cyrena* and other fresh-water forms, but with an admixture occasionally of brackish-water genera, such as *Ostrea, Modiola, Protocardia,* &c. This part of the series is comparable with the Middle Purbecks of the Dorset coast, while the underlying and overlying groups can be correlated with the Lower and Upper Purbecks of the same region.

The upper 240 feet of the division at Penshurst consisted mainly of dark laminated shales and greenish clay, with numerous bands of limestone, clay-ironstone and calcareous sandstone, in which we found fresh-water fossils only.

Portions of the above sequence were proved also in the Sub-Wealden boring and in a later boring at Heathfield Station (*see* p. 73), from which we may conclude that the central part of the Weald is probably everywhere underlain by Purbeck strata of this type. In the recent Battle boring, the Purbecks appeared to be about 460-470 feet thick, with the usual gypsiferous beds at the base, but the cores were unfortunately so perished by exposure before we had an opportunity to examine them, that we were unable to obtain palæontological proof of the estuarine episode.

At Pluckley, where the Purbecks were diminished to 100 feet, the greater part of the sequence resembled that of Penshurst, though much reduced in thickness. Gypsiferous beds occurred at the base and were overlain by compact flaggy claystones or marlstones; but above these beds there occurred a peculiar earthy breccia which was not found at Penshurst, and the similarity of the sections ceased above this horizon.

At Brabourne, where the thickness of the series was about 70 feet, the hard flaggy beds were still in evidence in the lower part, but without any notable development of gypsum at the base. Earthy breccia with claystone fragments, comparable to that noticed at Pluckley, was the most prominent feature in the higher beds, and was overlain by green and yellow mottled clay, approximately of the Wealden type. The breccia resembles that which occurs in the Purbeck group at Hartwell, Buckinghamshire. It was probably formed by the washing out of partly consolidated sediments on the drying mud-flats of a lake or estuary.

The Purbeck Beds mark the beginning of the great Wealden fresh-water basin which persisted thereafter until a late stage of the Lower Cretaceous period.

Wealden Series.

At Dover both the Weald Clay and the Hastings Beds were represented, yet the whole series was only 85 feet thick. At

Brabourne the same sequence was expanded to over 300 feet; at Pluckley to 1,000 feet, with the section still incomplete in the upper part; while at Penshurst, starting from a stratigraphical horizon at least 1,000 feet down in the series, there were yet 550 feet of Wealden strata to be penetrated. These figures illustrate the vast thickening of the sediments toward the middle of the basin, and roughly indicate the degree of earth-movement during the period. Only the broad division of the series—into an upper clayey portion=the Weald Clay, and a lower variable group containing more or less sand=the Hastings Beds—was found practicable in the complete sections. The minor subdivisions which have been recognised at the outcrop of the latter group could not be identified in the borings; nor was there much agreement between the details of the beds in the different sections.

At Penshurst the lowest beds were dark laminated shales and greenish clays with bands of ironstone and hard sandstone, hardly differing from the underlying Purbecks and containing the same abundance of fresh-water fossils. By gradual upward transition and alternation these beds became more sandy and less fossiliferous, containing for the most part the remains of plants and fish only, until in the upper 225 feet of the boring there was a predominance of soft yellowish sandstone, with subsidiary beds of clay, chiefly of the red-mottled type. The sandstones are identified at the outcrop as belonging to the Ashdown Sand, which is the lowest sandy subdivision of the Hastings Beds. The underlying mixed clayey group may be correlated with the Fairlight Clays of eastern Sussex, though only approximately resembling them in aspect.

At Pluckley, so far as the imperfection of the cores enabled us to judge, there was no sandy representative of the Ashdown Sand, the lower 225 feet of the Hastings Beds consisting of alternations of clays and shales, very varied in colour and composition, often sandy or silty, with numerous bands of concretionary claystone and ironstone; and above this, the remaining 85 feet of the division was composed mainly of sand and soft sandstone, probably equivalent to the Tunbridge Wells Sand of the outcrop. The upper part of the same boring consisted of 680 feet of clayey strata of variable character, which we have classified as Weald Clay; these beds contained the usual Wealden fresh-water shells, plants, &c., at a few horizons, but as a whole were scantily fossiliferous.

At Brabourne our classification shows the Hastings Beds reduced to 200 feet in thickness, made up of sandy silts, mottled red and green clays, darker clays and occasional stone-bands, with a bed of coarsish sand, 22 feet thick, about midway in the series. The Weald Clay was diminished to 109 feet in this section, and possessed a more laminated and less variable character than at Pluckley.

At Dover only 35 feet of strata of Hastings Beds type were present. At the base there was about 10 feet of coarse quartz-sand mixed with silt and pebbles, resting with signs of erosion directly upon the Kimmeridge Clay. This was probably a fluviatile deposit, due to the influx of a river from the north-east.

It differed from anything seen in the Penshurst and Pluckley sections, but was probably equivalent to the sand in the middle of the Hastings Beds at Brabourne, as there was a marked correspondence of characters in the overlying sequence to the top of the division at the two places, though every individual member was much reduced in thickness at Dover.

The 50 feet of Weald Clay which completed the Wealden series at Dover differed from its equivalent at Brabourne only in being more regularly and persistently laminated and more abundantly fossiliferous.

Atherfield Clay.

We have the Dover and Brabourne sections alone to deal with for the formations above the Weald Clay. At both places the entire sequence of marine deposits belonging to the later stages of the Lower Cretaceous period were exhibited, but it was only at Dover that the conditions were favourable for studying them.

The protracted fresh-water episode ended abruptly with the Weald Clay, and gave place to purely marine conditions. At Dover the slightly gritty base of the Atherfield Clay, the earliest of the marine sediments, rested directly on a perished surface of the Weald Clay, fresh-water fossils occurring plentifully right up to the junction, and a full marine fauna just above it. Though not so well seen there, the change appeared to be equally abrupt at Brabourne.

The Atherfield Clay was 43 feet thick at Dover, but appeared to be only about half as thick at Brabourne. It showed the same characters and fossils that it exhibits at its outcrop, being a smooth compact clay, partly chocolate-brown and partly bluish or greyish in colour, with numerous fossils chiefly in the state of beautifully delicate casts.

Sandgate Beds.

It is remarkable that although the Hythe Beds which succeed the Atherfield Clay at the surface can be traced persistently all round the Weald, and are the least variable beds of the Lower Greensand series, the subdivision could not be identified either at Dover or Brabourne. Either its lithological characters change rapidly northward in sinking underground, or sedimentation was in abeyance in the northern area during the time of its accumulation farther south. The latter supposition is favoured by the very substantial diminution shown, as a whole, by the Lower Greensands of the Dover shafts in comparison with their outcrop sections at Folkestone, and by the presence of a corroded surface, pitted with pholas-borings, at the top of the Atherfield Clay at Dover.

However this may be, the 80 feet of strata overlying the Atherfield Clay at Dover consisted wholly of beds of the Sandgate type —muddy glauconitic sands intermingled and banded with much dark pyritous clay. At Brabourne, the equivalent strata, about 100 feet thick, appeared to be of similar lithological character.

Folkestone Beds and Zone of *Douvilleiceras mammillatum*.

From their 60 feet at the Folkestone outcrop the Folkestone Beds had thinned away to 2 or 3 feet in the Dover shafts, where they were represented almost entirely by hard concretionary rock which showed a curiously irregular admixture of coarse pebbly grit, fragments of phosphate, bright large-grained glauconite and comminuted shells, all firmly cemented by crystalline calcite. This rock-band was overlain in places by a foot or two of clayey greensand containing many phosphatised casts of fossils, among which we found the characteristic zonal ammonite, *Douvilleiceras mammillatum*.

At Brabourne the Folkestone Beds were fully developed and in their usual form, consisting of 110 feet of coarse sand. The Mammillatus Bed appeared also to have expanded in this section to 6 or 7 feet.

Gault.

With the incoming of the Upper Cretaceous period, the persistent eastward thinning of the strata, which had continued almost uninterruptedly from the beginning of Mesozoic times, ceased at last; for the Gault showed a thickening of about 35 feet between the Dover shafts and its Folkestone outcrop. As explained elsewhere in this memoir (pp. 7, 99), our personal information respecting the Gault and the higher beds at Dover is so scanty that we cannot satisfactorily discuss them. The total thickness of the Gault at Dover was 135 feet. At Brabourne only the lower 62 feet of the formation was penetrated.

CHAPTER VII.

UNDERGROUND STRUCTURE OF THE MESOZOIC ROCKS.

General Notes.—In previous publications the results of the borings have been considered mainly with regard to the position and structure of the deep-seated Coal Measures. It is true that incidentally the chief factors in the development of the Mesozoic rocks have likewise been recognised[1], but this aspect will bear fuller consideration. Stress has been laid in the preceding chapters on the persistent westward thickening of nearly every Mesozoic formation below the Gault in our E—W line of section. From some published accounts of the borings that were not open to us, we gather that the expansion of the beds is still more rapid along any line drawn from north-east to south-west in East Kent.

The great thickening of the sediments in the Wealden area was made evident many years ago by the first Sub-Wealden boring. It is so pronounced that, in dealing with the question, Topley was led to conclude that the dome of the Weald itself was in part due simply to the differential piling up of the strata[2]. At first sight, the new results would appear to strengthen his argument, since the thickening is now proved likewise to affect lower formations than those known to him. But it has further been ascertained that the Palæozoic floor is depressed beneath the Weald to an amount which more than cancels the supposed doming effect in all the beds below the Wealden series, so that the argument really loses most of its force.

From the evidence of the borings we are enabled to trace the gradual development of this Sub-Wealden depression during successive periods, and to discriminate the effect of the later uplift by which the Wealden dome was established. In doing so, however, we must necessarily ignore or equalise out the possible effect of unknown faults, and must regard the boundaries of the formations as continuous planes.

Planes of Former Horizontality.

At several horizons in the sequence penetrated by the borings we meet with beds, or boundaries of beds, each of which may be safely assumed to have once been at the same level in all the localities where it occurs. In all such cases the present difference of level at different spots marks the net result of earth-movement since the plane was formed; and any lack of parallelism between successive planes of this kind must denote differential movement in the interval between their formation. The best example of a deposit from which former horizontality may be postulated is in the occurrence at separate spots of sediments laid down contemporaneously between tide-marks or in an estuary. There are

[1] *See* particularly, W. Boyd Dawkins in *Final Rep. Roy. Comm. Coal Supplies*, pt. x., 1905, pp. 30–1.

[2] "On the Correspondence between some Areas of apparent Upheaval and the Thickening of Subjacent Beds." *Quart. Journ. Geol. Soc.*, vol. xxx. (1874), p. 186. *See also* "Geology of the Weald," *Mem. Geol. Surv.*, pp. 241–2.

other cases not much inferior to this, some of which have been referred to in the preceding chapters. We can recognise in all at least eight such planes among the strata penetrated in our sections. These are, in ascending order, as follows:—

1. The Palæozoic floor, proved at Dover and Brabourne.
2. The Middle Lias, proved at Dover and Brabourne.
3. The Kellaways Rock, proved at Dover and Brabourne.
4. The Corallian limestones, proved at Dover and Brabourne.
5. The Portland sandstone, proved at Brabourne, Pluckley, and Penshurst.
6. The estuarine band of the Purbeck, proved at Brabourne, (? Pluckley), and Penshurst.
7. The top of the Weald Clay, proved at Dover and Brabourne.
8. The base of the Gault, proved at Dover and Brabourne.

The relation of these planes to each other is shown in the longitudinal section forming Pl. IV., on which they are indicated by thick lines numbered as above. They reveal the steady growth of the westerly depression till it reached its maximum at the close of Lower Cretaceous times. We will consider them further in the above order.

1. The Palæozoic Floor.

Numerous borings in the south-east of England have shown that this deeply-buried floor is an erosion-plane cutting across divers Palæozoic formations. Whether due to marine agency or to the weathering down of a land area, it appears to have been reduced to an approximately even surface, which was probably at first nearly horizontal. Early in Mesozoic times Triassic sediments were spread upon it, but how much of it was thus covered we cannot tell, as the old surface was pared down again in the north and east of Kent before the Lias was deposited; and it is only at Brabourne that Triassic rocks have been proved in the county. There are indications, however, that the westerly depression had already begun, and that the Trias of Brabourne is the fringe of a thicker mass lying in the depths to the south-westward.

In its present position, the Palæozoic floor is 590 feet lower at Brabourne than at Dover, which is equivalent to a westerly inclination of about 43 feet per mile. This is not the direction of full slope, however, as its depth in the borings at Fredville, Waldershare, and Ropersole[1], in relation to Brabourne, indicates that its south-westward inclination is slightly greater, amounting to 45-50 feet per mile.

It must not be forgotten that the present slope is the net result of successive movements, sometimes in one direction, sometimes in another, during the vast lapse of time since the old surface was first tilted. In the interval there have been periods when the inclination was less than it now is, and periods when it was greater. For example, the dip of the formations above the Wealden in this district is north-eastward, or reverse to the dip

[1] *See* Prof. W. Boyd Dawkins, *Final Rep. Roy. Comm. Coal Supplies*, pt. x., 1905, pp. 28–33; *also* Dr. M. Burr, *Science Progress*, no. 11, Jan., 1909, pp.1–31.

of the underlying Jurassic rocks and of the old floor beneath them (*see* Pl. IV.). Therefore the south-westerly dip of the lower strata must have been reduced since Wealden times by the later north-easterly tilting of the overlying Cretaceous rocks. At the beginning of Upper Cretaceous times, when the base of the Gault was horizontal, the Palæozoic floor must have been 998 feet lower at Brabourne than at Dover, instead of 590 feet as now; and its westward slope was then nearly 73 feet per mile instead of the present 43 feet per mile.

The depression in the south-west caused by the regional tilting appears to have had as its concomitant a relative uplift to the north-east of our line of section, so that a land area lay off this quarter during the greater part of Mesozoic times, with its shifting boundary sometimes remote from, and sometimes approaching or even entering the district under consideration. The absence of evidence for the earliest stages of the Lower Lias at Dover and Brabourne, and the unconformity at the base of the recognised portion of this formation in these places may be taken to indicate that at least the eastern part of our tract was above sea-level at the beginning of Liassic times. But a slow transgression of the sea from westward or south-westward was in progress, resulting from a depression of the district during the later stages of the Lower Lias; and marine conditions then continued until the Upper Lias was deposited.

2. The Middle Lias Level.

The clays and shales of the Lower and Upper Lias afford no certain indication of level, since they may have been deposited on a sea floor of variable depth. But, from the composition and close similarity of the ferruginous and sandy limestones at Dover and Brabourne, it may be assumed that these beds of the Middle Lias were accumulated at about the same depth in the two places. Postulating this, we have a measure of the relative subsidence of the Brabourne site in the fact that the strata between the top of the Middle Lias and the Palæozoic floor are 174 feet thicker at Brabourne than at Dover. For the country west of Brabourne we have no direct evidence, but there is every reason for supposing that the expansion of the Liassic and Triassic sediments is continued at no less a rate in that direction.

At the beginning of the Oolitic period the tilting appears again to have brought the eastern part of our area near to, or even temporarily above, sea-level; so that in the Dover district the upper part of the Lias was eroded and the coarse sands of the Lower Oolite were deposited. The absence of these shallow-water sands at Brabourne and their presence in some borings north-west of Dover indicate that the shore-line of the period had a north-westerly trend.

Most of the succeeding Lower and Middle Oolite sediments of the two sections yield evidence that the sea was generally deeper and less disturbed by currents at Brabourne than at Dover. The sandy Kellaways Rock, however, appears to indicate another stage at which temporary equality of depth was regained.

3. The Kellaways Rock Level.

The top of this formation is now 365 feet lower at Brabourne than at Dover, so that its westerly dip is decidedly less steep than that of the planes previously discussed. This is due to differential thickening of the underlying sediments which measure 433 feet to the Palæozoic floor at Brabourne but only 200 feet at Dover.

4. The Corallian Limestone Level.

There can be no doubt that the coral-reef limestones were formed at approximately the same level in relation to the sea of the period, and they afford us the next datum-line in the Dover and Brabourne sections. In the aggregate, the Middle Oolites below the top of the limestones are 51 feet thicker at the western site than at the eastern. Hence, at the Corallian level the present westerly depression of Brabourne is reduced to about 300 feet, or at the rate of only about 23 feet per mile.

Up to this level we have had only the two easterly sections to work with, as the two westerly borings did not reach below the Kimmeridge Clay. When the planes are plotted as in Plate IV., it is seen, however, that if they were prolonged westward without change of inclination we should have found the whole of the Upper and Middle Oolites in the Pluckley boring, and all above the lowest Corallian at Penshurst. Clearly, therefore, the slope of the depression must become steeper westward; of this we have, indeed, some direct evidence in the tilt of the Portland sandstone between Brabourne and Pluckley. Again, allowing that there may be a further 500 feet of Kimmeridge Clay at Penshurst beyond the 620 feet pierced in the boring, we find that the base of the formation will be at nearly 2,300 feet below Ordnance Datum there, as compared with 760 feet below O.D. at Brabourne and 500 feet below O.D. at Dover; and these figures give a slope of about 50 feet per mile on this plane between Penshurst and Brabourne, but only 19 feet per mile between Brabourne and Dover. Part of the difference may be explained by the fact that our chain of sections is not straight, but bends somewhat to the southward in passing from Pluckley through Brabourne to Dover (*see* Sketch-map, Fig. 1, p. 2). From what we can gather respecting the borings north of Dover, it seems fairly certain that if our section had run quite straight from Pluckley eastward, the Jurassic strata east of Brabourne would have shown a steeper westward slope on the diagram.

About the close of Jurassic times the uptilt in the north-east again brought the eastern part of our area above the rim of the sea-basin, so that some of the Upper Jurassic strata were pared down by erosion. If the Purbeck and Portland Beds were ever deposited at Dover, they were then removed, together with a large part of the Kimmeridge Clay.

5. The Portland Sandstone Level.

We have emphasized in previous chapters the fact that the Kimmeridge Clay exhibits westward expansion in a greater degree than any other formation of our sections except the

Purbeck-Wealden series. The formation, indeed, plays a most important part in the underground structure of the Weald, as it supplies the platform on which the Wealden dome is raised. By differential infilling, the western depression appears to have been practically obliterated at the close of Kimmeridgian times, since the Portland sandstone, which overlies the Kimmeridge Clay in the three westerly borings, was almost certainly deposited in shallow water at all three localities.

Between Brabourne and Pluckley the base of the Portland sandstone sinks westward at the rate of about 53 feet per mile; but the gradient becomes almost imperceptible in the extension from Pluckley to Penshurst, being at less than 2 feet per mile; and even this is obliterated, as will presently be shown, in slightly higher beds.

In the opposite direction, if the tilt of the Portlandian level between Pluckley and Brabourne be maintained eastward, on the rising side, it would bring about the outcrop of the formation at surface before Dover was reached. The actual outcrop is, of course, hidden under the later deposits in this quarter. Its probable position beneath the unconformable Hastings Beds is shown in the section, Pl. IV.

6. The Estuarine-Purbeck Level.

The recognition of a band containing estuarine fossils in the middle part of the Purbeck series at Brabourne and Penshurst gives us an assured datum-line for the original level of this formation. The position of the line can be fixed with close approximation at Pluckley also, by reference to other identifiable beds (*see* p. 60), although the distinguishing fossils were not detected there, probably because of the imperfection of the boring-cores.

The tilt of this plane between Brabourne and Pluckley is not appreciably different from that of the Portland Beds (only 1 foot per mile less). But between Pluckley and Penshurst we have to deal for the first time with a reversal of the direction of dip, the estuarine beds being about 165 feet *higher* at the latter place—equivalent to an *easterly* slope of about 7 feet per mile; and this easterly inclination is increased to 17 feet per mile at the top of the Purbecks, and to a still higher (but indeterminate) figure in the Wealden series.

The Reversal of Dip.

It is particularly noteworthy that this reversal of dip takes place at Penshurst between the upper and lower parts of a perfectly conformable sequence; and is here due entirely to the wedge-like distribution of the Mesozoic strata in the Wealden basin. The phenomenon would be still more strikingly displayed in a section orientated NE.-SW. or NNE.-SSW. across this part of the Weald, as the more rapid thickening of the beds along such a line would render the wedge more obtuse.

At Pluckley and Brabourne the reversal takes place between the bottom and top of the Wealden series. The upper part of the Weald Clay dips eastward in our line of section (this being the expression of a stronger NE. or NNE. dip which our

section cuts obliquely), while the lower boundary of the same formation has a westerly inclination between Brabourne and Pluckley. The division between the Weald Clay and the Hastings Beds is, however, so uncertain and conventional that it is unsafe to lay much stress on its position here, having in view the possibility that there may be some amount of lateral passage between the Wealden divisions. But there can be no question whatever that the reversal of dip is here established somewhere in the Wealden series.

7. The Top of the Weald Clay.

East of Brabourne, as we have seen, the Wealden base becomes a line of overlap and unconformity, cutting out the Purbeck, Portland, and part of the Kimmeridge beds before Dover is reached. In our section, this base-line has an eastward slope at the rate of about 5 feet per mile. By the greater thickness of the Wealden series at Brabourne the slope is increased to about 21 feet per mile on the plane at the top of the Weald Clay; and by a further thickening in the Lower Greensand it becomes 29 feet per mile at the base of the Gault.

8. The Base of the Gault.

The coarse sands of the Folkestone Beds, at the top of the Lower Greensand, were accumulated on the floor of a shallow current-swept sea at a depth which probably did not vary much in different places. Hence, the plane at the base of the Gault may be regarded as originally horizontal, though it must be admitted that the evidence for this condition is not so strong as in the case of the preceding planes. It is known that this horizon dips to NE. or NNE. in East Kent; and the calculated slope between Brabourne and Dover given in our last paragraph, being oblique to this direction, does not represent the full dip.

Everywhere below this plane we have found evidence of a continuous deepening of the westerly depression, both when the area as a whole was below sea-level, as during the greater part of the Jurassic period, and when it was above sea-level, as during the fresh-water Wealden and part of the Purbeck epochs. But with the submergence of the whole region at the beginning of the Upper Cretaceous period, a new set of conditions was inaugurated; the south-westward tilting ceased; and the subsequent movement was in the opposite direction.

If the base of the Gault once extended horizontally over the present Wealden district, as is implied by its field-relations, it is probable that the relative westward depression reached its maximum at that time. We can be certain that the Palæozoic floor was then at least 3,500 feet deeper at Penshurst than at Dover, and most likely even far deeper than this.

Concluding Deductions.

The eastward convergence of all the formational planes below the Gault, owing to the westward thickening of the strata, is clearly brought out in the diagrammatic section, Pl. IV. If prolonged eastward the planes would eventually meet, but

not at one point, since the ratio of thickening is unequal in the different formations. The majority will be found to intersect at distances varying from 15 to 25 miles east of Dover; and it seems a justifiable conjecture that their intersection indicates approximately the position of a border of the basin in which the deposits were accumulated. During a considerable part of Jurassic times, therefore, we may presume the presence of a shifting sea-border at about this distance to the eastward, which, however, after the Portlandian epoch, moved to the westward of Dover.

This coast-line appears to have had a north-westerly or west-north-westerly trend; and it is to the influence of off-shore currents sweeping along it that we assign many of the differences of composition and thickness between the Jurassic sediments at Dover and the borings farther westward. The evidence for persistent current action in the Dover sediments, on which we have laid stress in preceding chapters, may be thus explained.

The strike of the axis of tilting was probably parallel to this coast-line, or nearly so; and from the remarkable continuity of relative conditions in the basin we deduce that the axial line generally crossed our section somewhere near the Dover end, though its position changed from time to time within a definite belt. North-eastward of this axis the tilt caused relative uplift, complementary to the relative depression south-westward, so that the region as a whole was hinged, as it were, upon the axis.

Besides this pivoted movement, the area participated likewise in wider general movements of elevation and depression relative to sea-level, by which the boundaries of land and sea were shifted and the depth of water over the submerged tracts increased or diminished. These wider movements determined the character of the sediments as a whole, while the variation in the beds from place to place was brought about mainly by the local tilting.

These conditions ruled throughout Jurassic times and until the whole of the Wealden series had been packed down in the deepening basin. But after the Cretaceous period the old axis was obliterated; and new lines of movement were developed in Tertiary times, by which the present dome of the Weald was upheaved and a governing northerly or north-easterly dip imparted to all the formations which are now visible at the surface in Kent.

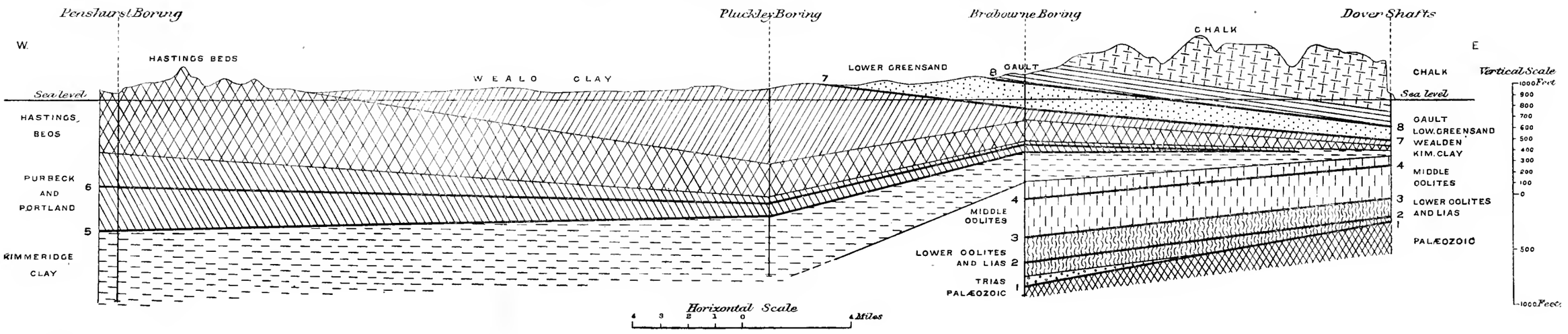
Thus, the Wealden dome, so far as its structure has been revealed by the borings, appears to be an anticline formed upon, or within the area of, an earlier syncline. The borings have proved that the great wedge of sediments beneath the dome had filled up the syncline with its Jurassic deposits, so that the anticlinal arrangement affects its higher formations alone. Nevertheless, this anticline, as shown by our section of its northern limb, is truly structural, and not due simply to the heaping up of sediments as Topley thought possible (p. 88).

The extremely slow and prolonged growth of the syncline, its final obliteration, and the exceptional persistence of the implied conditions within this small area, are the most impressive deductions arising from the study of these borings.

GENERALISED SECTION PASSING THROUGH THE FOUR BORINGS, ETC., ALONG THE LINE SHOWN ON THE SKETCH-MAP, FIG. 1, P. 2.

The thick black lines indicate planes of original horizontality described in Chapter VII., numbered as on p. 89.

Vertical scale much exaggerated (= *about* 21 *times the horizontal scale*).



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PART II.—THE PALÆONTOLOGICAL CHARACTERS AND CORRELATION OF THE STRATA BETWEEN THE GAULT CLAY AND THE TRIAS.

By F. L. Kitchin.

CHAPTER VIII.

INTRODUCTION.

When estimating the character of the fauna of any part of the strata passed through in the sections here dealt with, it is necessary that due allowance should always be made for the fact that the evidence is gathered entirely from borings or shaft-sinkings. All positive data thus acquired have their particular significance, while negative evidence, on the other hand, must be utilised with much greater caution. This is particularly so in the case of a boring of narrow diameter where only the fossils which chanced to be situated in the actual path of the boring-tool could be brought to light. In some instances, no doubt, individuals of a species, even when occurring fairly abundantly at a given horizon, may not be included in the cores, or if present in too small numbers may convey a false impression of rarity, or may even escape the eye of the collector. In the case of a shaft-sinking, while the amount of material brought to the surface from the larger area covered usually furnishes a truer picture of the life at any given level, yet the record obtained is sometimes less unbroken. At Dover, for example, where sinking operations were necessarily intermittent, it was not possible to obtain a view of the material brought up from all depths, and sometimes part of the rock which was excavated between the occasions of our visits was found to have been tipped within reach of the sea and to have been washed away. It has been necessary in a few such cases to complete the account as far as possible from information and specimens put before us by the engineer in charge. Where there was discontinuity in the record yielded by the borings, this was usually due either to the occasional use of chisel-tools or to the exposure of parts of the boring-cores upon an insufficiently protected storage-floor.

Against these disadvantages must always be weighed the important fact that the evidence obtained in the course of these explorations comes from continuous vertical sections in which the order of succession is fixed beyond question. In an area of low dips, where the sections comprise such a wide range of formations as in Kent, the palæontological data have a special value and a more precise significance than is usually the case with evidence procured from widely scattered surface exposures.

The remains of molluscs and brachiopods constitute by far the greater proportion of the fossils collected from the sections, but

these are precisely the forms amongst which many of the most familiar and most reliable guides to zonal position are to be found. As we might expect, the specimens were frequently fragmentary or obscurely preserved, often involving great difficulty in their identification. The importance of the ammonites in elucidating the zonal sequence in the Jurassic rocks is so great that it became necessary to pay particular attention to these, and in order that the best use should be made of the materials we have gathered together, the remains of Jurassic ammonites from Dover, Brabourne and Penshurst were submitted to Mr. S. S. Buckman, whose knowledge of the relationships and zonal distribution of these forms has enabled us to draw more precise conclusions than if we had utilised the materials without a specialist's help. Particularly was this so with the specimens from the Lower and Upper Lias and the zones of the Oxford Clay and Lower Corallian rocks. Some of the ammonites, however, notably amongst those from the Upper Kimmeridge Clay, are so imperfect and obscurely preserved that the naming must necessarily remain of a tentative character. In a few instances, where Mr. Buckman's attempts to indicate probable relationships may appear to suggest "zonal impossibilities," he states that in all likelihood his provisional naming is at fault, and that it must be accepted with due reserve. It will be necessary to refer to this point again as occasion arises.

The collections obtained from these Kentish sections contain not a few species which we believe to be undescribed, and many which might form the subject of critical and descriptive work; but the scope of the present memoir does not permit us to deal with these in the detailed manner which would be appropriate in a palæontological monograph. In the notes which follow each list of fossils we have made some brief reference to many of the species which are believed to be new, and have drawn attention to others which are of particular interest from the point of view of comparative stratigraphy, or which help to characterise the fauna at any particular horizon. There are others, however, of a more generalised kind which appear to have a remarkably wide range, particularly among the Jurassic lamellibranchs; but the recurrence of a name such as *Pteria* (*Oxytoma*) *inequivalvis* in the lists of fossils from various Jurassic formations must not be taken to indicate necessarily a true, unchanging persistence. No doubt zonal characteristics could be recognised in certain of the representatives of this widely distributed group of forms were the available specimens sufficiently well preserved[1], but the imperfection of our material has precluded a narrower classification. Similarly, for example, with the smooth specimens of *Pecten* (*Syncyclonema*) commonly referred to *P. demissus* Phill. In these there are so few zonally distinctive features and these are so insufficiently known, that an attempt to carry out a critical classification of imperfect specimens would be futile. It is also on account of the imperfection of the material that we must be content to

[1] L. Waagen. 'Der Formenkreis des *Oxytoma inaequivalve*, Sowerby,' *Jahrb. d. k.-k. geol. Reichsanst.*, Band li, Heft i, 1901, p. 1.

apply some generic names in a not too narrow or critical sense. Thus, for example, with certain Jurassic specimens referred to *Lucina*, it is clear that we must attach a broad sense to this name when the materials at hand so often show imperfectly the outward features and do not permit a study of internal characters.

This leads us to remark that in the application of generic and sub-generic names some usages will be found in the following pages which may for other reasons be open to criticism. We shall have occasion to observe that the employment of the name *Holcostephanus* for certain Portlandian and Kimmeridgian species is not in accordance with the recent view that the use of this name should be restricted to certain Lower Cretaceous forms. To rectify this would involve us in a detailed study of generic relationships which is beyond the limits of the present work. Other names, again, may be open to question on the ground of priority, but when dealing with such extensive suites of specimens the endeavour to avoid nomenclatural pitfalls might easily be permitted to result in an unprofitable consumption of time, and in a work of this character it becomes necessary to set some limits to that kind of research. If we retain such names as *Alaria* and *Modiola*, it is because we do not feel complete confidence in substituting *Dicroloma* in the one case and *Volsella* in the other[1].

Throughout the whole of the fossiliferous marine beds passed through, the lamellibranchs have furnished the most abundant and varied remains. In dealing with those from the marine Lower Cretaceous strata our task has been simplified by the advantage of having at hand a modern work in which many of these forms have been critically treated, the valuable monograph by Mr. H. Woods. It is otherwise with the Jurassic species of this class, for if we except the volume on the Mollusca of the Great Oolite by Morris and Lycett, and Lycett's memoir on the *Trigoniae*, there exists no work of monographic scope in which the Jurassic lamellibranchs of this country have been dealt with. It is fortunate that there is some compensation for this deficiency in the numerous systematic memoirs on Continental Jurassic Mollusca, particularly the works of the late Professor de Loriol on those of France and Switzerland.

The utility of recording generic names alone, or even doubtful generic determinations in the lists of fossils which follow, might be called in question; but in dealing with the materials from these deep-seated rocks when, particularly in regard to the borings, the chances of obtaining further specimens are at least doubtful, if not most remote, it is not easy to foretell what may or may not at some time prove to be of value. At the risk of burdening the lists, we have therefore decided to err on the side of safety. In some instances where at present a generic name only can be given, it might be possible, with further opportunities for study, to arrive at a specific identification, and thus perhaps add something material in a characterisation of the fauna of a given horizon.

[1] Mr. Jukes-Browne has pointed out some of the special difficulties which beset the search after a permanent molluscan nomenclature. A. J. Jukes-Browne. 'On some questions of nomenclature,' *Journal of Conchology*, vol. xi., no. 4, 1904, p. 97.

It is in the Jurassic rocks where we have encountered the greatest difficulties in selecting the formational boundaries, and since in some cases these are based upon palæontological characters alone and do not coincide with lithological changes, it is appropriate that the evidence upon which they are founded should be discussed in this portion of the work. For instance, the palæontological data have been found indispensable in the separation of the Oxford Clay from the overlying Corallian rocks, which in their lower part show, on the whole, no lithological differentiation from the underlying clayey series. Then again, the line of division between the Upper Corallian and Lower Kimmeridgian beds, though still arbitrary within certain limits, is much less so than it would have been if selected without the aid of the fossils. In a more marked degree has a study of the fauna been of value by enabling us to elucidate the succession in the Kimmeridge Clay and to throw light on the relations of a formation which is so unequally and perplexingly represented in the four sections described. The Kimmeridge Clay has presented special difficulties not only by the fact that it illustrates in the strongest degree that westerly thickening of the strata which is so striking a feature throughout a great part of the Mesozoic rocks of this region, but also because vastly different amounts of it are cut out above by unconformities at two of the localities—Dover and Brabourne. Owing to the great increase in the thickness of the clay when traced in a westerly direction and the fact that only the lowest beds of the Lower Kimmeridge Clay are present at Dover, it has followed that the clay at this locality is in no way comparable with any part of the great series passed through at Penshurst, where the Lower Kimmeridge Clay was never reached in the boring. Comparisons on purely stratigraphical grounds would have been rendered still more hazardous by the change of lithological characters, doubtless related to the position within the area of deposition, which is observable when the beds are traced from east to west.

As regards the comparative study of the faunas at various zonal levels and their correlation with Continental occurrences, it must be admitted that our opportunities have not permitted us to do full justice to this aspect of the subject. Whenever possible, the marine strata have been allocated, as nearly as may be, to their zonal position in a scheme based upon the occurrence of ammonite-remains, but when the evidence has been insufficient we have not attempted to force a narrow correlation with subdivisions elsewhere established in this manner. In the Lias and Oxford Clay the data obtained have permitted a fairly precise reference to ammonite-zones, but in the Kimmeridge Clay it has been necessary to be content with the recognition of broader subdivisions, though we are able to describe the changes which are clearly observable in the character of the fauna at successive horizons and to suggest the probable correlation with particular parts of the series as developed elsewhere.

The palæontological investigation of the rocks passed through in these sections has necessarily been limited to a consideration of those beds from which we have succeeded in obtaining fossils

worthy of study. We were able to make no collections from above the base of the Gault, and have had no opportunity of examining any suite of specimens found in that formation at Dover which might be of use for our present purpose. Specimens from the Gault obtained by the late R. Etheridge are without record of the depths at which they occurred, and are consequently of little or no value for the present purpose. As regards the strata below the Lias, the boring-cores from the Triassic beds passed through at Brabourne have furnished no traces of contemporaneous life.

Following the method of arrangement adopted in the previous part of this work, the palæontological features of the strata, taken in descending order, are discussed separately under the heading of each of the four sections described, passing from the most easterly locality, Dover, to the most westerly, Penshurst. The general results are brought together in a final summary in which the strata are passed in review in ascending order. The detailed arrangement which is followed throughout with reference to any particular part of the sequence provides, firstly, some remarks of a general character, or it may be some considerations relating to the bearing of the fauna upon stratigraphical subdivisions, and then a list of the fossils which is followed by any observations or elucidatory notes on the species which may seem to be required. In the lists of fossils the depths are quoted from which were obtained the actual specimens studied, and it is perhaps scarcely necessary to give a word of warning lest these figures should be permitted to convey a too precise meaning. In many cases they can give no true indication of the actual vertical distributions, though they may sometimes prove to be of great value in this respect, where perhaps least suspected. While their absolute value in relation to distance from the surface is frequently of little account, their use in showing the relative positions of species in the sequence is in certain cases of great moment, and sometimes the need for still greater precision in recording the relative depths has been much felt. When a single figure is given enclosed within brackets, this indicates that the depth recorded has been ascertained with approximate correctness. When two depths are given connected by a line—for example, 250-300—the species in question has been found to occur at the extreme depths quoted and also between them; but if these connected figures be enclosed within brackets—for example [250-300]—this means that the specimens were found at some depth which cannot be precisely indicated between the extremes mentioned.

Throughout the lists of fossils which follow, the names of authors of species are placed within parentheses when, in the original description of the species, a different generic name was employed.

CHAPTER IX.

THE DOVER SINKINGS.

Zone of *Douvilleiceras mammillatum.*

The thin band representing this zone yielded fairly abundant casts of Mollusca, more or less phosphatised, and more sparing remains of brachiopods, crustaceans and the teeth of fishes. The character of the fauna as revealed here is quite in agreement with that shown by the Mammillatus Bed near Folkestone, and it may be said that there are stronger palæontological relations with the Gault above than with the Lower Greensand. This is shown not only by the ammonites, but also by the bivalves, and this change is already faintly foreshadowed in the Sandgate Beds below, so far as can be judged from their imperfectly known bivalve-fauna. The ammonites obtained from the Mammillatus Bed at Dover include, in addition to the name-fossil of the zone, a *Desmoceras* allied to *D. beudanti*, and also one of the highly ornamented species of *Hoplites* (*sensu stricto*), quite distinct from *H. benettianus* (J. de C. Sow.), or *H. interruptus* (Brongn.).

Fossils from the Mammillatus Bed; depth about 300 *feet.*

Kingena spinulosa (*Morr.*)
Rhynchonella gibbsiana (*J. de Sow.*)
Terebratula sp.
Cardita?
Cucullaea obesa (*Pict. and Roux*)
Cyprina quadrata *d'Orb.*
Grammatodon carinatus (*J. Sow.*)
Inoceramus salomoni? *d'Orb.*
Nucula albensis *d'Orb.*
Pecten (Syncyclonema) orbicularis *J. Sow.*
Pecten (Chlamys) sp.
Plicatula gurgitis *Pict. and Roux*
Thetironia minor (*J. de C. Sow.*)
Aporrhais?
Cerithium?
Dentalium decussatum? *J. Sow.*
Nautilus sp.
Ancyloceras *cf.* tuberculatum (*J. Sow.*)
Desmoceras *aff.* beudanti (*Brongn.*)
Douvilleiceras mammillatum (*Schloth.*)
Hoplites *cf.* raulinianus (*d'Orb.*)
Hoploparia sp.
Lamna? [tooth]
Odontaspis sp. [tooth]

It has been pointed out by Messrs. Newton and Jukes-Browne that the common species of *Desmoceras* which occurs in the Mammillatus Bed near Folkestone is apparently very closely related to *D. beudanti* (Brongn.), but that it differs by having a rather more complex lobe-line, as regards finer details, and also by the fact that it always has a series of constrictions[1]. Numerous

[1] E. T. Newton and A. J. Jukes-Browne, in Jukes-Browne. 'The Cretaceous Rocks of Britain, vol. i., Gault and Upper Greensand' (*Mem. Geol. Surv.*), 1900, p. 443.

specimens found in this bed at Dover all belong to the ligated form, and are identical with the ammonites found at the same horizon at East Wear Bay, Folkestone, to which Messrs. Newton and Jukes-Browne drew attention. Those authors decided to regard this form as a variety of *D. beudanti*, and they proposed to call it *D. beudanti*, var. *ligatus*. They state that *D. beudanti*, while occurring in the Gault above, has not been found in the Mammillatus Bed; and although it has been quoted as one of the fossils from the Mammillatus Zone at Wissant[1], there does seem to be some doubt whether it made as early an appearance as the ligated form with which we have to do at Dover and Folkestone. There is, therefore, some degree of probability that this ammonite has been classified as a " variety " of a species which appeared later. Moreover, the choice of the name *ligatus* is unfortunate, and in the event of specific rank being accorded to this form the use of the name would be certain to introduce confusion with d'Orbigny's *Ammonites ligatus*, likewise a *Desmoceras*.

Parona and Bonarelli included *Desmoceras beudanti* in their genus *Cleoniceras*[2], but there is such good general agreement between the lobe-line of *Ammonites cleon* d'Orb. (type of *Cleoniceras* Par. and Bon.) and that of *Ammonites latidorsatus* d'Orb. (type of *Desmoceras*, as previously restricted by de Grossouvre)[3], that the necessity, or even the advisability of instituting a separate genus with *Ammonites cleon* as type does not appear to us to be clearly evident. It must be admitted that *D. beudanti* is characterised by a simpler type of lobe-line than *D. latidorsatum*, but the general disposition of lobes and saddles, and the number of these, does not differ. For the present we may, therefore, leave both the true *D. beudanti* and the form here discussed in the genus *Desmoceras*[4]. As regards the probable nature of the relationship between the two it is difficult to form a definite opinion, particularly as the material at our disposal from the Mammillatus Bed, although fairly plentiful, is somewhat fragmentary. In the presumably earlier form, weakly sigmoidal constrictions are a constant feature, but apart from this the more strongly fretted lobes and saddles are a distinguishing character. It is probable that this form should be accorded separate specific rank, but there is undoubtedly close relationship to *D. beudanti*, while there is great uncertainty whether the two stand related in a direct line of descent and some probability that they do not.

A specimen of *Hoplites* entered as *H.* cf. *raulinianus* in the above list shows some general agreement of characters with the figure of *H. raulinianus* given by d'Orbigny[5], but differs in

[1] A. J. Jukes-Browne, *op. cit.*, p. 379.

[2] C. F. Parona and J. Bonarelli. 'Fossili Albiani d'Escragnolles,' *Palaeontographia Italica*, vol. ii., 1896, p. 83.

[3] A. de Grossouvre. 'Recherches sur la Craie Supérieure ; Paléontologie des Ammonites de la Craie Supérieure,' *Mém. pour servir à l'Explicat. de la Carte Géol. de la France*, 1894, p. 166.

[4] Reasons for and against this union, and the rival claims for the application of the names *Desmoceras* and *Beudanticeras*, cannot be discussed here. See remarks by P. Lemoine. *Rev. Crit. de Paléozoologie*, 1911, no. 3, p. 181.

[5] A. d'Orbigny. 'Paléontologie Française. Terr. Crét.,' tome i, 1840–42, pl. lxviii.

several particulars. The specimen is of rather smaller size than the one depicted by d'Orbigny, yet in the last half of the last whorl preserved the ribs have ceased to proceed in couples from the tubercles at the umbilical margin, and the ribbing has acquired a much greater instability of type. There is more irregularity in the size and spacing of the obliquely compressed tubercles at the peripheral margin. While each tubercle at the umbilical margin gives rise to a rib, intermediate ribs also appear, though not with regular order, taking rise on the flank at some distance away from the umbilicus. Some of the shorter ribs thicken rapidly towards the periphery and terminate in a marginal tubercle as strong as those of the main ribs. The lobe-line has a general agreement with that of *H. raulinianus*, but is less complex in its details. This form probably belongs to an undescribed species. From the relative instability shown in the disposal of the ornaments it may be considered to illustrate a more advanced developmental type, as regards ribbing, than *H. raulinianus*, but it shows a somewhat less advanced stage in suture-development.

Folkestone Beds.

Comminuted fragments of shells and other organisms were found in the few feet of strata which are taken to be a very condensed representative of the Folkestone Beds, but nothing was seen which could give any idea of the fauna. The only recognisable remains found were a small *Pecten* and the internal cast of a highly turreted gasteropod, probably either *Pseudomelania* or *Cerithium*.

Sandgate Beds.

Very few fossils could be recovered from the Sandgate Beds, and they include no remains of cephalopods, but only some lamellibranchs and gasteropods which contribute but little to a zonal characterisation. Not only were fossils found to be scarce, but the conditions of preservation were most unfavourable for their extraction from the soft muddy greensands. Those shells which had escaped complete destruction were in a soft and somewhat incoherent state, so that many of them crumbled away. Others suffered during the drying of the impure matrix, and the application of preservative methods was only partially successful. The few species found include lamellibranchs of considerable interest. Two or three are referable to *Meretrix* (*sensu lato*), and show characters which appear to exclude them from any of the narrower generic divisions hitherto recognised as occurring in the Cretaceous rocks of this country. These deserve more attention than can be devoted to them in this memoir. One species of *Astarte* which has a peculiar shape belongs most probably to an undescribed form, while two others can only be referred to species which have hitherto been known solely from the Blackdown Greensand.

The basement bed illustrates the work of boring shells on the underlying floor of Atherfield Clay in a beautiful manner. Specimens taken from the junction show numerous crypts of borers, some of the holes exceeding three inches in length and having a diameter towards the lower end of nearly one and a half

inches. These burrows were made by at least two lamellibranch-species, to judge by the remains found in them. Most commonly a species of *Pholadidea* was the occupant, but occasionally the shell of *Panopea mandibula* was found retaining the position of life and corresponding so well with the size of the crypt as to leave no doubt that it was the actual borer. This may be taken to indicate that the floor of Atherfield Clay, although of such firm consistency that the crypts are sharply defined, was so soft as to offer little resistance. It appears more probable that the *Panopea* should have been capable of boring into this material than that the shell of a *Pholadidea* could have been removed from its burrow and have been accidentally replaced by a *Panopea* of suitable size.

Fossils from the Sandgate Beds; depth, from a little below 300 *feet to about* 388 *feet.*

(a). The upper 50 feet.

Depth in feet.	
[311—327]	Rhynchonella sulcata *Dav.* [? *d'Orb.*]
[310], [311—327]	Astarte (Eriphyla) concinna *J. de C. Sow.*
[311—327], 320	„ „ striata *J. de C. Sow.*
[310]	„ „ sp. nov. ?
[311—327]	Cardita ?
[320]	Corbula striatula *J. de C. Sow.*
[311—327]	Lima (Acesta) longa *F. A. Roem.*
„	„ (Mantellum) *cf.* parallela (*J. Sow.*)
„	Meretrix [sensu lato] sp. 1.
„ [320]	„ „ sp. 2.
„	Pecten (Chlamys) robinaldinus ? *d'Orb.*
„	Pholadomya fabrina *d'Orb.*
„	Trigonia *cf.* aliformis *l'ark.*
320, [350]	Natica genti (*J Sow.*)

(b). The basement bed at about 388 feet.

Cardita ? fenestrata (*Forbes*)
Panopea mandibula (*J. Sow.*)
Pecten (Syncyclonema) orbicularis *J. Sow.*
Pholadidea sp. nov.

The shells of *Astarte* referred to *A. (Eriphyla) striata* show exact agreement with specimens from Blackdown. It has been possible to lay bare the hinge of both valves and to show the presence of a weak sublunular hinge-process in the left valve. An allied form, having a highly elevated oblique outline, is referred to *A. (Eriphyla) concinna*, which has hitherto only been known by the type specimen from Blackdown. In the absence of further material, Mr. H. Woods in 1906 concluded that *A. concinna* may be looked upon as an individual variation of *A. striata*[1], but in view of the presence in this collection from the Sandgate Beds of several individuals which show constancy in the shape-characters, it may now be recognised that the Blackdown shell named *A. concinna* is really specifically distinct from *A. striata*. The Dover specimens show very close agreement, and

[1] H. Woods. 'A Monograph of the Cretaceous Lamellibranchia of England,' vol. ii., part 3, 1906, p. 118. *Palæontographical Society.*

may, we think, be referred to Sowerby's rarer species. A single individual occurring with the last near the top of the Sandgate Beds has characters which are somewhat intermediate between the two last-named. It is inequilateral and much less nearly suborbicular than *A. striata*, and it is considerably less elevated in figure than *A. concinna*. The umbo is situated posteriorly to the middle. The antero-dorsal slope is long and much less steeply inclined than in *A. concinna*. The valves are covered by a fine concentric linear ornamentation similar to that of the other two species. This is probably a representative of some undescribed form.

Two species assigned in the above list to *Meretrix* were represented by many individuals, but only a few examples could be secured in a sufficiently perfect condition to show the characters of the hinge, upon which the finer classification of these and allied forms is principally based[1]. One of these, *Meretrix sp.* 1, is an elongated shell having considerable convexity; it may measure 30 mm. in length by 21 mm. in height at the umbo. There is a slightly sunk lunule. In the outline this shell shows some resemblance to *Cyprimeria* (*Cyclorisma*) *faba* (J. de C. Sow.) of the Gault of Black Ven and Greensand of Blackdown; but the Dover specimens are more strongly inflated and show essential differences in the hinge. The cardinal teeth of the right valve bear a closer resemblance to those of *Dosiniopsis*; there is a strong, oblique, bifid, posterior cardinal tooth in that valve, and an elongated anterior lateral in the left valve parallel with the lunular margin. The specimens named *Meretrix sp.* 2 in the list are much less elongated in figure. They bear some outward resemblance to *Cyprimeria* (*Cyclorisma*) *parva* (J. de C. Sow.), but are more elevated in outline. The shell is similarly produced in front of the umbones, but in a stronger degree than in *C. parva*. Were it not for the regularly convex posterior outline, the valves would have a sub-quadrate figure. The hinge of the right valve is almost identical with that in *Meretrix sp.* 1. There is a very oblique, strong, bifid posterior cardinal tooth in this valve, and under the lunule is an elongated pit parallel to the margin for the reception of a lath-like anterior lateral tooth of the left valve. It is probable that a third species is also represented in the material collected. The remnant of a left valve shows a higher and shorter outline than that of species 2, but the specimen is not sufficiently perfect for thorough comparison. These forms require a closer study than can at present be devoted to them, and as they cannot be readily placed in the generic scheme set forth by Mr. Jukes-Browne they may be temporarily referred to *Meretrix* (*sensu lato*).

The specimens of *Pholadomya* ascribed to *Ph. fabrina* are of larger size than the type figured by d'Orbigny, but resemble it in shape and in the distribution of the ribbing over so large a part of the valves. One example obtained measures 60 mm. in length by 38 mm. in height. It is a cast of both valves, almost uncrushed, with thin traces of shell adhering.

[1] *See* A. J. Jukes-Browne. 'Genera of Veneridae in Cretaceous and Older Tertiary Deposits,' *Proc. Malac. Soc.*, vol. viii., part 3, 1908, p. 148.

The examples of *Pholadidea* from the basement bed are poorly preserved casts, with only faint traces of the shell itself. They measure as much as 35 mm. in length by 28 mm. in height at the umbo. Some individuals are relatively more elongated than this, and may have suffered some crushing, but it is not improbable that two species are represented. In all the specimens there is a deeply marked, oblique sulcus passing back from the umbonal region to the inferior margin, and the surface of the valves is ornamented by regularly spaced, concentric linear ribs, placed about one millimetre apart from one another. There is some resemblance to *Pholadidea koeneni* (Woll.)[1], but that species differs somewhat in shape and also by the presence of well-marked radial ribbing in the anterior region of the valves.

Atherfield Clay.

The Atherfield Clay at this locality has furnished a wealth of palæontological material, for the most part lamellibranchs. The fossils are chiefly preserved as delicate casts, often showing slight adhering traces of the original shell in the case of those species which possessed a strong nacreous layer. The specimens of *Pecten* and of oysters, however, have their shells well preserved. It is probable that the causes which removed the shell of other genera were active at the time when deposition had just taken place, very shortly after the embedding of the specimens; for it seems less likely that the shells would be exposed in any marked degree to destroying agencies after becoming finally sealed up in the firm, impalpable clay. Yet there are indications that a certain degree of solidification of the matrix had been reached before the removal of the organic carbonate of lime, for many of these beautiful specimens show the features of the internal surface of the shell together with some of the finest details of external sculpture also impressed upon the cast. Thus, internal casts of *Cardium ibbetsoni* which retain no remnant of the shell-substance exhibit the fine serration on the radial ribbing of the posterior part of the valves, while *Thetironia minor* shows traces on the casts of the delicate punctate sculpture of the original surface. An internal cast ascribed to *Thracia rotundata?* also bears the imprint of the most delicate external markings, and examples of this mode of preservation might be multiplied. It therefore seems probable that after the removal of the shell-substance by solution, the pattern of the external mould thus formed became imprinted upon the surface of the internal cast by compression, at a time when the clay was somewhat firm though still plastic[2].

The topmost bed, perforated by the borings of Mollusca belonging to the overlying Sandgate Beds, contained many casts of *Pholadomya* and also yielded *Hoplites deshayesi*, which was

[1] A. Wollemann. 'Die Bivalven und Gastropoden des deutschen und holländischen Neocoms,' *Abhandl. der k. preuss. geol. Landesanst.*, Neue Folge, Heft 31, 1900, p. 146, pl. vii., fig. 2.

[2] Compare V. Hilber. 'Ueber Sculptursteinkerne,' *Verhandl. d k.-k. geol. Reichsanst.*, Jahrg. 1878, no. 11, p. 226.

found to be distributed throughout the whole thickness of the clay. Other species found in the uppermost five feet were *Lima* (*Mantellum*) *sp.*, *Nuculana scapha*, *Panopea mandibula*, *Thracia rotundata?* and *Odontaspis sp.* (tooth), as well as indeterminable fragments of fish.

The deposit was seen to be richly fossiliferous throughout, but here and there the specimens were clustered together more thickly, particularly so below the depth of 418 feet, where *Pinna robinaldina* was so numerous that we can speak of the occurrence of a *Pinna*-bed. The majority of the specimens which form the basis of the following list were collected from the clay between this depth and the base at about 431 feet, but it must not be concluded that species were confined to those levels in the clay from which examples were actually brought away. It is probable that few, if any, of the forms could have been shown to be narrowly restricted to any particular part of the clay even if collecting could have been carried out in a more detailed manner and extended over a wider area. There is no indication in the ammonite-remains found at the base and near the top that the deposition of the whole 43 feet of beds was spread over any considerable extent of time, and accumulation probably took place steadily and comparatively rapidly under placid conditions which permitted unretarded sedimentation.

It is difficult to institute any minute comparison between the Atherfield Clay as here developed and the corresponding strata in the Isle of Wight. It is noteworthy that no specimen was seen at Dover of the large species of *Perna* which occur in the Perna Bed of that district, and it is not unlikely that the junction here between the Weald Clay and the overlying Aptian beds does not coincide very strictly in position with the base of the Lower Greensand in the Isle of Wight. With regard to the great abundance of *Pinna robinaldina* at Dover below a depth of 418 feet, it may be remarked that although this species occurs in the Perna Bed of the Isle of Wight, yet its particular abundance in the lower part of the clay overlying this was noticed by Fitton[1]. It is not improbable that the palæontological distinction between the Perna Bed, the Atherfield Clay and the overlying "Crackers" is much less marked than might be supposed from the early published lists of fossils from them, and at Dover we find some species in the lowest 10 feet of the clay which were noted by Fitton as making their first appearance in the Crackers.

The remains of cephalopods found in the clay at Dover form a typically Aptian assemblage such as occurs in France and Germany. It is scarcely possible to say definitely whether the lowest part of the Aptian as developed in North Germany is represented here; but it is probably not, since there are beds seen at one locality (Timmern) which according to G. Müller and Stolley underlie the *Hoplites deshayesi* Beds and do not yield

[1] W. H. Fitton. 'A Stratigraphical Account of the section from Atherfield to Rocken End, on the South-west coast of the Isle of Wight,' *Quart. Journ. Geol. Soc.*, vol. iii., 1847, p. 296.

that species, though it should be stated that according to von Koenen there is some little doubt about the correlation of that lowest zone[1]. It may be noted, however, that we believe one of the ammonites from Dover, which is associated with *H. deshayesi*, to be identical with *Hoplites laeviusculus* v. Koen., also found in the lowest zone at Timmern. It is perhaps more significant that *H. deshayesi* is commoner at a higher level in the North German Aptian than near the base as known at Kastendamm, where that species is also found, and it is the higher beds that von Koenen has spoken of as the Deshayesi Beds proper. To judge from the common occurrence of this fossil at Dover, it was the dominant form of cephalopod-life, and it was so abundant that a correlation with the position of its observed maximum in continental localities is strongly suggested.

Fossils from the Atherfield Clay; depth, 388 *feet to about* 431 *feet.*

Depth in feet.	
415	Micrabacia sp.
[418—431]	Enallaster fittoni *Forbes*
420	Pseudodiadema fittoni *Wright*
[418—431]	Serpula sp.
410	Rhynchonella gibbsiana (*J. de C. Sow.*)
430	Anomia laevigata *J. de C. Sow.*
425—430	,, pseudoradiata *d'Orb.*
420—431	Barbatia aptiensis (*d'Orb.*)
[418—431]	,, austeni (*Forbes*)
[420—430]	Cardita? fenestrata (*Forbes*)
418—431	Cardium ibbetsoni *Forbes*
420–431	Corbula striatula *J. de C. Sow.*
420	Cyprimeria (Cyclorisma) parva (*J. de C. Sow.*)
[418—431]	Cyprimeria? [common]
,,	Cyprina (Venilicardia) protensa? *Woods*
[425]	Exogyra boussingaulti (*d'Orb.*)
415, [420—430]	,, conica *J. de C. Sow.*
431	,, sinuata (*J. Sow.*)
415—430	Gervillia forbesiana *d'Orb.*
420—430	Grammatodon *cf.* securis (*Leym.*)
[420—430]	Isocardia angulata *Phill.*
415, 420, [418—431]	Lima (Mantellum) parallela (*J. Sow.*)
393	,, ,, sp.
415	Lucina sp.
,,	Modiola aequalis *J. Sow.*
[430]	,, ligeriensis? (*d'Orb.*)
430	,, subsimplex (*d'Orb.*)
420—431	Nucula planata *Desh.*
390, 420—430	Nuculana scapha (*d'Orb.*)
[418—431], 425	Panopea gurgitis (*Brongn.*)
388, 393, 420—431	,, mandibula (*J. Sow.*)
410—430	Pecten (Neithea) morrisi (*Pict. and Ren.*)
[418—431]	,, (Syncyclonema) orbicularis *J. Sow.*
,,	Pharus warburtoni (*Forbes*)
420, [418—431]	Pholadomya martini? *Forbes*
[388]	,, sp. [specimens not collected]
418, [425]	Pinna robinaldina *d'Orb.*

[1] A. von Koenen. 'Ueber das Auftreten der Gattungen und Gruppen von Ammonitiden in den einzelnen Zonen der unteren Kreide Norddeutschlands,' *Nachricht. d. k. Gesellsch. d. Wiss. zu Göttingen, Math.-phys. Klasse*, 1907, p. 7 (of author's copy).

Depth in feet.	
420	Plicatula placunea *Lam.*
415, 420	Protocardia peregrina (*d'Orb.*)
[418—431], 430	Tellina sp.
415—430	Thetironia minor (*J. de C. Sow.*)
415	Thracia robinaldina ? (*d'Orb.*)
393	„ rotundata ? (*J. de C. Sow.*)
430	„ sp.
420, [420–430]	Trigonia etheridgei *Lyc.*
415	„ ornata *d'Orb.* [immature]
415—430	Unicardium ? sp. nov.
[418—431]	Actaeon sp.
„	Alaria fittoni (*Forbes*)
415—430	Aporrhais glaber (*Forbes*)
420	„ sp.
431	Patella sp.
[420—430]	Solarium dentatum ? *d'Orb.*
415	„ minimum *Forbes*
[418—431]	Nautilus plicatus *Fitt.*
410	*Cf.* Acanthoceras albrechti-austriae *Uhlig*
415	Crioceras sp.
„	Douvilleiceras martini ? (*d'Orb.*)
388—431	Hoplites deshayesi (*Leym.*)
[418—431]	„ (Hoplitides) laeviusculus *von Koen.*
[430]	Hoploparia sp. [fragment]
430	Meyeria sp. „
420	Pollicipes sp.
431	Acrodus ornatus *A. S. Woodw.*
„	Hybodus basanus *Ag.*
390, 420	Odontaspis sp.
393, 431	Fish fragments.

The specimen brought into comparison with *Acanthoceras albrechti-austriae* is a fragment of a large individual which in its coarse and irregular ribbing shows good agreement with the figure given by von Koenen of an ammonite which he has thus determined from the lowest part of the Aptian at Kastendamm[1]. The example from Dover shows only the faintest traces of any nodes near the umbilical margin, but it represents an advanced stage of growth, in which the nodes would have much less definition than at earlier stages. It may well be identical with the North German form.

Among the specimens referable to *Hoplites deshayesi*, two are fragments showing an advanced stage of growth comparable with that illustrated by Neumayr and Uhlig in a large specimen from the Aptian of North Germany[2]. The chief difference observed is that in the Dover examples, the primary ribs at the umbilical rim are rather more widely spaced. The allied *Hoplites weissi* Neum. and Uhl. has a similar type of ribbing, but it is distinguished by still narrower spacing of the costæ. In recent years there has been a great tendency to restrict the application of the name *Hoplites* to closer and closer limits, and the work of Uhlig, Baumberger and others has shown the necessity of introducing a number of new generic names for many Lower Cretaceous species which were formerly referred to *Hoplites*. As

[1] A. von Koenen. 'Die Ammonitiden des norddeutschen Neocom,' *Abhandl. der k. preuss. geol. Landesanst.*, Neue Folge, Heft 24, 1902, pl. xli., fig. 1.

[2] M. Neumayr and V. Uhlig. 'Ueber Ammonitiden aus den Hilsbildungen Norddeutschlands,' *Palæontographica*, Band xxvii., 1881, pl. xlv.

evidence regarding the minuter relationships of these ammonites is being accumulated, a more natural and rational classification is gradually taking shape. Uhlig has expressed the view that the geologically important group of *H. deshayesi* and *H. weissi*, which he believes do not occupy a place in the direct line as forerunners of the true, richly ornamented *Hoplites* (*sensu stricto*) of the Gault, ought to be assigned to a new genus[1].

A crushed cast of a form with broad peripheral area and umbilical marginal nodes is referred with doubt to *Douvilleiceras martini*. Peripheral ribs proceed in couples from the nodes and there are occasional intermediate ribs also. The specimen resembles one of the figures included by d'Orbigny under this name[2], and if correctly assigned to this species it represents a stage prior to that at which peripheral nodes make their appearance. There is resemblance to one of Forbes's figures of his *Ammonites hambrovi*[3], but specimens of that form of comparable dimensions show greater inequality in the size of the peripheral ribs and greater irregularity in their arrangement. Examples of an ammonite from Hythe, which shows close agreement of characters with the Dover specimen, have usually been referred to *A. martini*.

A fragment of *Crioceras* from a depth of 415 feet is a small portion of a large individual. It has an ornamentation of almost straight ribs which increase steadily in thickness towards the periphery. In the style of the ribbing there is much resemblance to *Crioceras aegoceras* von Koen.[4], but the costæ are more widely spaced at corresponding dimensions in that form. The ribs of this fragment are much too closely spaced for reference to the coarsely-ribbed stage of *Crioceras bowerbanki* (J. de C. Sow.) or *C. hillsi* (J. de C. Sow.).

Casts of lamellibranchs probably referable to *Cyprimeria* were numerous in the lower part of the clay, but were generally more or less distorted by crushing, and it is impossible to determine them with certainty. It is not unlikely that most of these may be *C. parva*, to which some uncrushed examples certainly belong, to judge by their shape[5].

The specimens referred to *Exogyra boussingaulti* are beautifully preserved and agree precisely with examples from Lympne.

Casts of *Pholadomya*, which are flattened by crushing, are of rather larger size than specimens usually assigned to *Ph. martini* Forbes. Their crowded ribs show a regularly nodular character,

[1] V. Uhlig. 'Einige Bemerkungen über die Ammonitengattung *Hoplites* Neumayr,' *Sitzungsber. d. k. Akad. Wiss., Math.-Nat. Classe*, Band cxiv., Wien, 1905, p. 629. *Also*, 'Himalayan Fossils, vol. iv. The Fauna of the Spiti Shales,' p. 182, 1910. *Palæontologia Indica*, Ser. xv.

[2] A. d'Orbigny. 'Paléontologie Française. Terr. Crét.,' tome i, 1840-42, pl. lviii., fig. 9 only.

[3] E. Forbes. 'Catalogue of Lower Greensand Fossils,' *Quart. Journ. Geol. Soc.*, vol. i., 1845, p. 354, pl. xiii., fig. 4.

[4] A. von Koenen, *op. cit.*, pl. xxxvi.

[5] H. Woods. 'A Monograph of the Cretaceous Lamellibranchia of England,' vol. ii., part 5, 1908, pl. xxviii., figs. 19-23, pl. xxix., figs. 1-3. *Palæontographical Society.*

due to the intercrossing of growth-ridges. There is resemblance to *Ph. martini* in the very inequilateral form of the valves, but owing to the paucity of material from Dover and of undoubted *Ph. martini* from other localities, and also in view of the fact that the shells of *Ph. martini* are nearly always distorted by crushing, a final determination is scarcely possible.

The casts of *Protocardia* which we have identified as *P. peregrina* (or *peregrinorsa*) show good agreement with d'Orbigny's figure[1]. Mr. H. Woods was not able to decide from the material at his disposal that this species actually occurs in the Atherfield Clay, and he pointed out that Forbes's identification of Atherfield specimens with d'Orbigny's species was doubted by Pictet and Campiche[2]. The possible relationship to *P. forbesi* (Pict. and Ren.), suggested by Pictet and Campiche[3], is not borne out by a comparison with the figures of *P. forbesi* given by Pictet and Renevier[4], which show that their species is less rounded and more nearly triangular in outline and is further distinguished by a much more strongly developed and prominent umbonal region.

A single somewhat crushed cast of a lamellibranch from near the top of the clay is believed by Mr. Woods to be probably *Thracia rotundata*[5]. This rare species has fine linear transverse ribs on the area and still finer radially directed ribbing on the remaining part of the valves. The example from Dover shows these delicate markings very clearly. Casts of an unornamented species, believed by Mr. Woods to be also referable to *Thracia*, were found at the base of the clay. This form, which has apparently never been described, has an elongated, almost equilateral shell measuring about 50 mm. in length and 23 mm. in height at the umbonal region.

Casts of a lamellibranch of doubtful affinities, which Mr. Woods refers with some hesitation to *Unicardium*, occurred not infrequently between a depth of 415 feet and the base of the clay. The specimens, which have generally suffered some flattening by crushing, have a sub-quadrate outline, and are marked by fine broken concentric ridges, giving a wrinkled appearance to the surface. Typical valves measure 35 mm. in length and 22 mm. in height at the umbonal region. There is a very close resemblance to the figure of a specimen from the Lower Kimmeridge beds of the Haute-Marne, ascribed by de Loriol (as *Lucina*) to Roemer's *Mya rugosa*[6]. In the absence of the shell

[1] A. d'Orbigny. 'Paléontologie Française. Terr. Crét.,' tome iii., 1844–48, pl. ccxxxix., figs. 1–2.

[2] H. Woods, *op. cit.*, vol. ii., part 5, 1908, p. 195, footnote.

[3] F. J. Pictet and G. Campiche. 'Descript. des Fossiles du Terr. Crét. des environs de Sainte-Croix,' *Matér. pour la Paléont. Suisse*, Ser. 4, p. 255, 1866.

[4] F. J. Pictet and E. Renevier. 'Descript. des Fossiles du Terr. Aptien de la Perte du Rhone,' *Matér. pour la Paléont. Suisse*, Ser. 1, p. 79, pl. viii., fig. 4, 1856.

[5] Mentioned, H. Woods, *op. cit.*, vol. ii., part 6, 1909, p. 242.

[6] P. de Loriol, E. Royer and H. Tombeck. 'Descript. géol. et paléont. des étages Jurass. Supér. de la Haute-Marne,' *Mém. Soc. Linn. Norm.*, Tome xvi., 1872, p. 266, pl. xvi., fig. 1.

and of any knowledge of the internal characters it is difficult to discuss the relationships of these specimens. Mr. Woods considers that they belong to an undescribed species. They are well distinguished by their shape and peculiar ornamentation and deserve further attention. Thanks are due to Mr. Woods for the favour of his opinion regarding some of the above-mentioned lamellibranchs which have presented difficulty in their determination.

Of the few fish remains yielded by these beds, named by Mr. E. T. Newton, the specimens referred to *Acrodus* and *Hybodus* came solely from the base of the clay and are probably derived fossils from the underlying Weald Clay.

Wealden Series.

(1.) weald clay.

The fossils found in the Weald Clay at Dover comprise only a small number of species compared with the abundance of individuals met with, and for the most part they were found to be in poor preservation. The assemblage is of typical Wealden character and calls for no special remark. There is no observable difference in the general character of the invertebrate fauna found at different levels in the clay, and some of the commoner species were seen to be distributed almost throughout the whole series; fish remains, however, were more numerous in the lower half of the formation. As is common in Wealden and other fresh-water deposits, many of the bedding surfaces are covered with the remains of some single species, of ostracods or molluscs as the case may be, almost to the exclusion of others. Ostracods, as usual, are present here in great numbers, but beyond the fact that the few species identified belong to typical and well-known Wealden forms, they do not call for further remark.

Fossils from the Weald Clay; depth, about 430 *feet to* 480 *feet.*

Depth in feet.	
445, 480	Weichselia mantelli (*Brongn.*)
470, 480	Plant remains and lignite
440	Cyrena media (*J. de C. Sow.*)
440, [460]	,, obtusa? *F. A. Roem.*
445	,, sp.
440	Unio *cf.* compressus *J. de C. Sow.*
[460]	,, ?
440, 470	Viviparus elongatus (*J. de C. Sow.*)
[438—444], 440	,, sp.
,, 450	Cypridea spinigera (*J. de C. Sow.*)
470, [470—478]	,, tuberculata (*J. de C. Sow.*)
438—480	,, valdensis (*J. de C. Sow.*)
,,	Metacypris fittoni (*Mant.*)
470	Acrodus ornatus *A. S. Woodw.*
[470—478]	Hybodus subcarinatus *Ag.* [dorsal spine]
[438—444], 470	,, sp. [defence and other fragments]
460, [470—478]	Lepidotus sp.
450, 460, 470	Fish remains [jaw bones, Pycnodont teeth, and other fragments]

The specimens of *Cyrena* referred with doubt to *C. obtusa* occur very numerously, but they are not well preserved. The valves have the umbones well advanced towards the anterior end and there is a convex postero-dorsal margin. Some examples show fairly good agreement with Roemer's figure[1], but when compared with the figures given by Dunker[2], most of our specimens differ in being more rounded and less nearly angular postero-ventrally, and rather more inequilateral. Yet the general characters seem to unite them more closely with *C. obtusa* than with other described species.

Examples of *Unio* found associated with *Viviparus* at a depth of 440 feet are flattened out on the bedding-surfaces with only a thin remnant of their nacreous layer preserved. Yet it is probable that these elongated shells had never a strongly convex form, and they closely resemble *U. compressus* in shape[3].

The fragments of fishes obtained from these rocks have been named by Mr. E. T. Newton, who believes that the remains of a little jaw from a depth of 450 feet may be new.

(2.) HASTINGS BEDS.

The fossils of the Hastings Beds were scanty and consisted mainly of ostracods and fragments of fish contained in the occasional seams of tough black clay among the pale silts; of plant-remains, mostly indeterminable, in some of the loams; and of a few fragmentary saurian bones in the pebbly beds. Of the last mentioned, two or three pieces were seen, but we did not secure specimens. The beds differ notably from the overlying Weald Clay in the absence of molluscan remains. Among the relics of plants we may mention the remnant of an underground tuber, perhaps belonging to *Equisetites*, and a fragment of resin, both obtained from the pale silts in the middle of the series (depth 500 feet). Of the other fossils we have no determinations worthy of record.

KIMMERIDGE CLAY.

The junction between the Hastings Beds and the Kimmeridge Clay in this section has been described in a previous chapter, and it was stated that the uppermost bed of the clay here presents an eroded surface upon which the Hastings Sands were deposited. The question as to how late in Jurassic times sedimentation actually continued at this locality has also been discussed, and it remains now to state the result of the palæontological comparison of these Kimmeridge Beds at Dover with the series revealed in the more westerly borings.

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[1] F. A. Roemer. 'Die Versteinerungen des norddeutschen Oolithen-Gebirges,' 1839, pl. ix., fig. 7*b*.

[2] W. Dunker and H. v. Meyer. 'Monographie der norddeutschen Wealdenbildung,' 1846, pl. xii., figs. 2, 2*a–c*.

[3] J. de C. Sowerby. 'The Mineral Conchology of Great Britain,' vol. vi., pl. 594, fig. 2, 1828.

We see that at Brabourne the Kimmeridge Clay is divisible into an upper series of clays and a lower less purely argillaceous series. The upper clays have their own distinctive fauna by which, apart from lithology, they stand in marked contrast to the lower clays. The lower clays are characterised throughout their whole thickness by the presence of *Exogyra virgula* (*sensu lato*) and by associated forms such as *Gervillia kimmeridgensis* which were not met with in the upper clays. At the same time, certain species which were of frequent occurrence in the Upper Clays were not found in the Virgula Beds below.

It is quite certain that the Kimmeridge Clay at Dover must be correlated with part of the lower division or Virgula Beds at Brabourne. In the first place its lithological character shows much closer agreement with the Virgula Beds than with the more purely argillaceous overlying clays. It is true that the significance of this lithological comparison might be considered to be reduced when we bear in mind that the easterly attenuation of the beds is accompanied by some change of lithological facies, such as may be associated with shallower water conditions. But a study of the fossils obtained at Dover places beyond doubt the question of correlation. From the top of the Kimmeridge Beds here we obtained "*Holcostephanus*" cf. *desmonotus*, *Exogyra virgula*, *Gervillia kimmeridgensis* and *Nucula menkei*, and lower down *Ostrea deltoidea*, all of which were found in the Virgula Beds at Brabourne, though not above them. Negative evidence in such cases must be carefully handled, but it is most significant that although we have to do with the more plentiful material from a shaft-sinking and not with a boring-core, yet the typical species of the Upper Clays in the Brabourne boring were not seen at Dover. Thus, there was no evidence for the presence of *Modiola autissiodorensis*, *Astarte* cf. *mysis*, *Aporrhais* cf. *piettei*, or *Protocardia morinica*, which, except the last-named—which occurred chiefly in the upper division, were found only in those higher beds at Brabourne. "*Holcostephanus*" *pallasianus?* and the species of *Perisphinctes* of the Upper Clays were also not seen at Dover.

While the evidence for placing the highest Kimmeridge Clay at Dover with the Virgula Beds at Brabourne is sufficiently clear, we may also note some points which suggest very strongly that the whole of the Virgula Beds as represented at Brabourne are not present at Dover. It has been a question whether the erosion which removed the deposits of Post-virgula age may or may not have swept away some of the upper Virgula Beds also. Indications that this has in reality happened may be recognised in the following facts. *Protocardia morinica*, which occurred in the cores from the uppermost 60 feet of the Virgula Beds at Brabourne, was not found at Dover. *Gervillia kimmeridgensis* and *Nucula menkei* were not met with in the cores from so high as the top part of the Virgula Beds at Brabourne, but occurred at the very top at Dover. *Astarte ingenua*, which occurred in the upper half of these beds at Brabourne, and very numerously in some bands, was entirely absent at Dover so far as our materials are a guide. Near the top of the Virgula Beds at Brabourne

there is a bed containing the crowded shells of large clavellate *Trigoniae*, and we might expect that this *Trigonia*-bed would have attracted attention at Dover had it been present; but no specimen of a comparable form was noted. *Pecten* cf. *kimmeridgensis* was seen at Brabourne only below the very base of the Kimmeridge Clay, in fact just in the uppermost part of the strata we have classed there as Corallian, but examples of this species were present at Dover not far from the top, as well as lower down. Then there is "*Holcostephanus*" cf. *desmonotus* which, while occurring in the top bed at Dover, was only seen at Brabourne from the lowest ten feet of Kimmeridgian cores. In addition, it must be noted that *Modiola perplicata*, which was found at a depth of 20 feet below the top of the clay at Dover, is cited by de Loriol only from the Corallian in the Boulonnais, and not from higher strata. *Ostrea gregaria* also, which is found in the top bed at Dover, suggests a close proximity to Corallian strata, where it is a dominant species. It may be observed that oysters of this type, and probably inseparable from *O. gregaria*, are only cited (as *O. rastellaris*) from the Sequanian in the Boulonnais. It must be admitted that, making due allowance for elements of chance, significance may reasonably be attached to the above facts when their cumulative weight is considered; and viewing the data at present available, we may conclude that the Virgula Beds are here incomplete in their upper part, compared with those at Brabourne. Further, we think it highly probable from the palæontological evidence that the uppermost 60 feet of Virgula Beds at Brabourne are unrepresented here, and we therefore believe that the beds at Brabourne which actually correspond with those preserved at Dover are about three times as thick as at this locality. Hence it may be concluded that about 20 feet of the Virgula Beds are missing at Dover.

The top bed of the Virgula Clays was found to be very fossiliferous, and since the assemblage seen here is of interest in relation to the above discussion, the names of the fossils are given below in a list separate from that in which the species from the underlying beds are set forth.

In relation to the classification adopted by Mr. H. B. Woodward for the Kimmeridge Clay of England, these beds at Dover may perhaps best be correlated with the sub-zone of *Ostrea deltoidea* and a portion of the overlying sub-zone of *Exogyra virgula*; but owing to the local changes of facies, it is difficult to make a close correlation between these Kentish Lower Kimmeridge strata and corresponding beds on the continent. It is probable that they include all or nearly all of that portion of the series where, in some districts, a Pterocerian facies is developed, as well as some small part of the continental Upper Sequanian. The ammonites have been compared with species of the Tenuilobatus Zone, and it seems certain that we must not place many feet of the series, if any, above the Orthocera Beds of continental authors. We see that *Exogyra virgula* is common only in the upper 15 feet or so. With regard to the lowest beds, we are unable to say how much of the uppermost Sequanian (in Pellat's sense) in the Boulonnais is represented; but it is not

improbable that our base-line falls at a slightly lower level than Pellat's division between Lower Kimmeridge and Sequanian in that district. The question as to where the basal line of the formation should be drawn at Dover and Brabourne is one of some difficulty, and this matter is discussed below in the remarks which precede the lists of fossils from the Corallian Series.

It has been repeatedly stated that *Exogyra virgula* is a species of such apparently erratic distribution that it is unreliable as a guide-fossil. The exact zonal position where it appears in greatest force in different districts is perhaps a variable one within certain limits, depending upon local conditions. This species has been noted as occurring in Upper Corallian beds, and we see that in Kent its range, if the species-name be not restricted to the higher and more typical forms, extends downwards to the very base of the Kimmeridge Clay and that even below this individuals are met with which, while not of such frequent occurrence as to characterise the strata in the manner observed in higher beds, and not large typically formed valves, may be regarded as smaller forerunners. In the Boulonnais the species was stated by de Loriol and Pellat to appear first in the corresponding upper Sequanian beds, though rarely. It was more common in the overlying Pterocerian strata and increased in numbers and size until its maximum was found in the "Virgulien" series above (Caletanus and Erinus Beds). Those authors, however, record its occurrence also in the overlying base of their lowest "Portlandien," within the beds of the Gigas Zone.

In the Kentish sections, so far as our evidence goes, the upward range is seen to be abruptly defined. It is at Brabourne, where all the beds with *Exogyra virgula* are present, that this restriction of range can be best observed, for at Pluckley the material was insufficient for detailed collecting; and when we come to deal with the palæontology of the Brabourne section the matter will be further discussed. It remains to be explained here that this species is of such value in characterising the fauna of the whole of the lower beds, below those yielding *Modiola autissiodorensis*, that we are led to make use of it by referring to this lower part of the series under the general term "Virgula Beds." The term as thus used must not be allowed to introduce confusion with the "Virgulien" of the Boulonnais as defined by Pellat. We see that at Dover our Virgula Beds are roughly equivalent to Pellat's Pterocerien, for in all probability the overlying Caletanus Beds of his Virgulien are in great part or wholly absent; while at Brabourne the Virgula Beds no doubt include the equivalent of these higher strata also. Thus by the name Virgula Beds we refer to the strata characterised by the frequent presence of *Exogyra virgula* and not only to that part of the series where it finds its maximum; for by the nature of the evidence before us, the position of such a maximum in these Kentish rocks cannot be very accurately tested. At the same time, the indications, so far as they go, are quite compatible with a maximum occurrence in the upper part of our "Virgula Beds," in a position corresponding with the maximum observed in the Boulonnais. At Dover, where greater reliance

can be placed on the evidence than in the case of the more restricted material from Brabourne, the species was notably rarer in the lower beds of the series.

Fossils from the Virgula Beds; depth, 515 *feet to* 560 *feet.*

(a). From the top bed; depth, about 516 feet.

Pentacrinine columnals
Orbiculoidea sp.
Astarte *cf.* supracorallina *d'Orb.*
Exogyra virgula (*Defr.*)
Gervillia kimmeridgensis *d'Orb.*
,, *cf.* linearis *Buv.*
Grammatodon *cf.* rhomboidalis (*Cont.*)
Nucula menkei *F. A. Roem.*
Ostrea (Alectryonia) gregaria *J. Sow.*
Pecten (Camptonectes) sp. nov.
Pholadomya protei? *Brongn.*
Pteroperna gervillioides (*Cont.*)
Trigonia monilifera? *Ag.*
Cerithium?
Natica sp.
" Holcostephanus " *cf.* desmonotus (*Oppel*)
,, *cf.* lepidulus (*Oppel*)
Mecocheirus?

The very fossiliferous blue clay, which forms the top bed here, contained numerous obscure casts of lamellibranchs and gasteropods within a few inches of the upper eroded surface. Many of the specimens which form the basis of the above list are preserved as casts, but some show traces or films of the original shell. Two examples of *Pteroperna gervillioides* were collected, and it is probable that this species was not rarely represented. It was not found in the underlying beds, and its absence from the Brabourne cores may be most probably accounted for by the element of chance. The same may be said of other species which were not seen in the corresponding part of the cores at Brabourne. Such are *Ostrea gregaria,* and the representatives of *Grammatodon, Pecten, Astarte, Orbiculoidea,* and obscure crustacean remains perhaps referable to *Mecocheirus,* mentioned in the above list. There are also species found in the beds below this at Dover which were not seen in the corresponding cores at Brabourne, but the resulting differences in the lists from the Virgula Beds of the two localities do not introduce any element of conflict with the evidence of the leading fossils common to both sections; and in viewing the fauna as a whole, the additional forms found at Dover must be regarded as supplementary to those seen at Brabourne.

The *Grammatodon* noted in the above list is not identical with the form which we have recorded by the same method of naming from the Post-virgula clays at Penshurst. The single specimen found at Dover has both valves in place and is in the form of a cast with some altered traces of the shell adhering. The shell has less relative height posteriorly than Contejean's figures of *G. rhomboidalis,* and it is proportionately more elongated. The umbonal regions of its valves are broader, more massive and more prominent. It differs from the Penshurst form, of later age, by

the presence of radial ribs on the frontal region, as well as in other features. Of the published figures of comparable species in which radial ribbing on the flanks is not a characteristic, perhaps Contejean's illustration of *G. rhomboidalis* shows the closest resemblance[1].

The species of *Pecten* (*Camptonectes*) is represented by one valve in our collection, measuring 45 mm. in height and about the same in length. Only thin remnants of the original shell are preserved, but these show that the ornaments consist of crowded, fine, radiating and diverging linear striæ crossed by numerous concentric lines. Such traces of the shell as remain show a tendency to the formation of concentric, downwardly imbricating laminæ, and if the preservation had been more favourable, these might perhaps have been projected as definite concentric ridges. The whole ornamentation, if the shell were more perfect, would strongly recall that of a specimen figured by de Loriol under the name *Pecten lamellosus*, from Post-virgulian beds near Boulogne[2]. In that, however, the concentric ridges are more widely spaced. It is quite probable that both the Dover specimen and the later examples from Boulogne are representatives of a *Camptonectes*-stock just such as that from which *Pecten lamellosus* J. Sow. of our Portland Beds was derived. It will be recalled that in *P. lamellosus* the fine, linear, radial ornaments, which extend over the whole surface in the earlier forms, have become pushed back and confined to an immature stage of growth, and that the massive character and the irregularity of the succeeding concentric ornaments suggest degenerate, phylogerontic features.

The specimens here named *Gervillia kimmeridgensis* d'Orb. are, we believe, identical with the form figured by de Loriol under Roemer's name *G. tetragona*. They represent a species which has usually been referred to *G. aviculoides* (J. Sow.) by writers in this country, but doubt has been expressed by some Continental authors whether it is really identical with Sowerby's species. This is a question which can only be settled by a careful investigation, and is a matter rather for discussion in a palæontological monograph than in this memoir. While leaving the question of its correctness an open one, we use this name for those shells which have been figured by de Loriol as *G. tetragona*, which de Loriol considered to be identical with d'Orbigny's species; because we are inclined to doubt their identity with the German form. In the Haute Marne and the Boulonnais their distribution was found to be in the Virgulian (Caletanus and Erinus Beds), the Pterocerian and the Sequanian. At Dover and Brabourne this form occurs throughout our Virgula Beds, and specimens were also seen just below the base of the Kimmeridge Clay at Brabourne. The species attains importance in the Kentish sections by reason of the fact that, in its distribution as here known to us, it does not occur

[1] Ch. Contejean. 'Étude de l'Étage Kimméridien,' 1859, pl. xvii., figs. 8, 9.
[2] P. de Loriol and E. Pellat. 'Mon. pal. et géol. de l'étage Portl. des environs de Boulogne-sur-Mer,' *Mém. Soc. Phys. et d'Hist. Nat. Genève* vol. xix., part 1, 1866, pl. x., fig. 4.

above our Virgula Beds, and was not found below them except just immediately beneath the base-line we have drawn at Brabourne.

(b). From between 518 feet and 560 feet in depth.

Depth in feet.	
518	Pentacrinine columnals
,,	Pygurus sp.
[520—530]	Serpula sulcata *J. de C. Sow.*
540	Lingula ovalis *J. Sow.*
518	Terebratula subsella *Leym.*
,,	,, sp.
540	Arca sp.
,,	Ceromya inflata *Ag.*
,,	Exogyra nana (*J. Sow.*)
518, [520—530]	,, virgula (*Defr.*)
[550—555]	,, *aff.* ,,
518, 535	Gervillia kimmeridgensis *d'Orb.*
[550]	Lima (Plagiostoma) rigida? (*J. Sow.*)
535	Nucula menkei *F. A. Roem.*
535. 540	Modiola perplicata (*Etallon*)
535	Opis *cf.* suprajurensis *Cont.*
[550]	Ostrea deltoidea *J. Sow.*
518, [550]	,, (Alectryonia) gregaria *J. Sow.*
540, [550]	,, ,, sp.
[520—530], [550]	,, sp.
518	Pecten (Syncyclonema) demissus? *Phill.*
[520—530], [550]	,, (Chlamys) *cf.* kimmeridgensis *Cott.*
535	Pholadidea compressa (*J. de C. Sow.*)
[520—530], 535	Pholadomya acuticostata *J. de C. Sow.*
[520—530]	,, paucicosta *F. A. Roem.*
535	Pinna sp.
540	Pleuromya recurva? (*Phill.*)
[520—530], 540	,, sp.
538	Thracia?
545	Trigonia monilifera? *Ag.*
538, [550]	,, *cf.* voltzi *Ag.*
[540]	Cerithium muricatum? (*J. de C. Sow.*)
[520—530]	"Holcostephanus" *cf.* molenai *Canav.*
540	,, *cf.* stephanoides (*Oppel*)
[520—530]	,, *cf.* trimerus (*Oppel*)
,,	,, witteanus (*Oppel*)
[520—530], 535	,, *cf.* ,,
[550—555]	Crustacean
518	Fish scales

Exogyra virgula was found most commonly in the material from the upper part of this series, and, in fact, below a depth of 530 feet no specimen was collected which is undoubtedly referable to this species. The doubtful example found below 550 feet is a valve of small size, not displaying the typical aspect of the larger specimens found in the highest beds. We shall see that at Brabourne also, the valves ascribed to this species which were obtained from the lower beds were of correspondingly small size.

Exogyra nana, Pholadomya acuticostata, and *Modiola perplicata* may be regarded as links with the Corallian lamellibranch-fauna, and were not collected from any depth above 540 feet.

Specimens of *Pecten* which we bring into close comparison with *Pecten (Chlamys) kimmeridgensis* (Cott.) occurred from a depth below 520 feet downwards to the very base of the series, where they became more numerous. They were also seen at Brabourne

in still lower beds. Their absence from the cores in the Virgula Beds at that boring can obviously have no significance in the question of zonal range or lateral distribution. This *Pecten* is particularly characteristic. It permits of very close comparison with the figures of Cotteau's species, which occurs in the Virgulian (Caletanus Beds) of the Haute Marne[1], thus at a higher horizon, we believe, than that at which the highest occurrence of the Dover examples was noted. Were it not that the right valves of our specimens show a greater inequality in the size of the ears and a deeper byssal notch, we should have been disposed to identify them definitely with Cotteau's species. The left valves appear to show entire agreement, and there seems to be no other described *Pecten* to which our specimens bear such close similarity. The leading features of the sculpture consist in very delicate and numerous radial ribs crossed by more widely spaced concentric lamellar ridges, less well marked or dying out in the middle region of the valve. The lamellar ridges are more prominently developed in the left than in the right valve, where they are sometimes scarcely noticeable, but variation in the degree in which these ridges are present in either valve is to a large extent dependent on the state of preservation. Thus, the absence of the ridges in a few individuals must almost certainly be ascribed to unfavourable preservation.

Ostrea deltoidea was found only near the base of the series, and it will be seen that it occurred also in a correspondingly low position at Brabourne.

The remains of ammonites, which were found to be much more rare than the lamellibranchs, were in a condition which did not permit of very satisfactory identifications. The specimens here referred provisionally to *Holcostephanus* have not been generically defined in accordance with the modern view that this name should be used in a restricted sense for a well-circumscribed group of Lower Cretaceous forms—the group typified by *H. astierianus* (d'Orb.). We shall see that the same remark applies also to certain species in the Post-virgula beds in the other sections dealt with in this memoir; but a discussion of the generic classification of these forms cannot be entered into in these pages, and for the purpose of our lists the provisional naming given may suffice.

If the above list of ammonites should be thought to point to a lower zonal position than that indicated by a consideration of the whole fauna and its relation to the underlying and overlying occurrences, we must make allowance for the insufficiently precise correlation of the Tenuilobatus Zone as developed in Aargau and Ardèche with corresponding beds in north-west Europe. A specimen ascribed by Mr. Buckman to "*Holcostephanus*" *witteanus* occurred at a depth between 520 feet and 530 feet, thus at a considerable distance above the base of our Lower Kimmeridge Clay. But that species was stated by Oppel to come from the "Scyphienkalke," that is, from a horizon which he at one time

[1] P. de Loriol, E. Royer, and E. Tombeck. 'Description géologique et paléontologique des étages Jurassiques Supérieurs de la Haute Marne,' *Mém. Soc. Linn. Norm.*, tome xvi., 1872, p. 381, pl. xxii., fig. 4.

believed to correspond with a position relatively far down in our Corallian Series. Again, in the case of the specimens compared with "*Holcostephanus*" *trimerus*, this form was found in the same ten feet of strata as the above, and it is referred for close comparison with a species from the Tenuilobatus Zone.

It must be recognised that Oppel at first referred the Tenuilobatus fauna to a position considerably too low in the series, though at a later date, while leaving the question of its exact age unsettled, he suggested a probable correspondence with the Lower Kimmeridge Clay[1]. Moesch and de Loriol considered the Tenuilobatus Zone of Argovie (Badener Schichten) to illustrate a local facies of the Upper Sequanian or Astartian of other districts[2]. But even though the Baden Beds may represent in a condensed series so extensive a range of time as to correspond with a part of our Upper Corallian as well as some of our Lower Kimmeridgian strata, those authors apparently did not succeed in giving a full interpretation of the facts. For it is quite evident that some of the species from the Tenuilobatus Zone belong to horizonal positions well within the Pterocerian of French authors, that is to say, in a part of our true Lower Kimmeridge Clay, and in certain cases they may represent levels as high up as the Orthocera Beds. Therefore no anomaly is introduced by the reference of these ammonite-remains from our Lower Kimmeridge Clay to species of the comprehensive Tenuilobatus Zone. A real difficulty arises, however, by the reference of certain specimens from the Upper Kimmeridge Clay of Brabourne and Penshurst to species of that broad zone, and this will be duly noted in the remarks which follow the lists of fossils from the higher levels at those localities.

Corallian Series.

When we come to consider, from the point of view of stratigraphical classification, the palæontological features of the series of beds below those of undoubted "Virgula" character and above the Corallian Limestone, we are met by considerable difficulty. The fact is that at this locality the contrast between the fauna of the Corallian Limestone and that of the 90 feet or so of beds overlying it is intensified by the abrupt change of lithological facies. This implies a change in life-conditions which altered the aspect of the fauna in a greater degree than would be accounted for by the difference of age alone, had the conditions remained more constant. The collecting of fossils from these beds which we are classifying as Upper Corallian could not be carried out as thoroughly as might be desired, but enough was obtained to

[1] A. Oppel. 'Ueber jurassische Cephalopoden,' *Pal. Mitth. Mus. d. k. bayer. Staates*, vol. i, p. 188, 1863.

[2] P. de Loriol. 'Monographie Paléont. des couches de la zone à *Ammonites tenuilobatus* (Badener Schichten) de Baden (Argovie),' *Mém. Soc. Pal. Suisse*, vol. v., 1878. *Also*, 'Monographie Paléont. des couches de la zone à *Ammonites tenuilobatus* (Badener Schichten) d'Oberbuchsitten et de Wangen (Soleure),' *Mém. Soc. Pal. Suisse*, vols. vii. and viii., 1880–1. C. Moesch. 'Der Aargauer-Jura,' pp. 178–192. *Beitraege zur geol. Karte d. Schweiz*, Lief. iv., 1867. *Also*, 'Der südliche Aargauer-Jura,' pp. 81–89. *Beitraege zur geol. Karte d. Schweiz*, Lief. x., 1874.

illustrate the contrast with the limestone-beds below and to show that the fauna, when traced upwards into the Virgula Beds, passes up without any sudden change of general aspect.

Viewing the fauna in the light of the combined evidence obtained at Dover and at Brabourne, its characters may the more readily be compared with those of the overlying Virgula Beds. The question of correlation between the Upper Corallian strata at these two localities is not difficult, and is simplified, moreover, by the occurrence at both places of the characteristic millet-seed ironstone which, there is no reason to doubt, occurs at the same horizon at both places. We see, then, that the assemblage of fossils, consisting largely of lamellibranchs, is chiefly distinguished from that of the lowest Kimmeridge Beds by the prevalence of *Exogyra nana*. Specimens which appear very closely united with *Exogyra virgula* certainly occur sporadically down to the ironstone, but they are of small size and are not typical in character. *Gervillia kimmeridgensis* was not met with except in the uppermost few feet at Brabourne, while *Ostrea deltoidea* was not seen, and the presence of *Nucula menkei* is only suggested by a very doubtful specimen from the ironstone at Brabourne. At Dover, at the horizon of the ironstone, spines of *Cidaris* were found, and one of these is so strongly reminiscent of *C. smithi* that we refer it to that species, and thus the Corallian age of the fauna is most strongly suggested.

One can have no difficulty in deciding to class the beds up to the ironstone as Corallian, but it must be admitted that to draw the line between Corallian and Kimmeridge Clay at any given point in the section above this becomes a matter for more arbitrary choice. The change noted in tracing the fauna upwards is such a gradual one that it seems almost immaterial at precisely what level a dividing line, which at present must be a conventional one, shall be drawn. The line we have chosen, at a depth of 560 feet at Dover and 973 feet at Brabourne falls, however, below that level at which *Exogyra virgula* was a prevalent fossil.

While these Upper Corallian Beds may without hesitation be brought into close comparison with those in Dorset, where the Abbotsbury ironstone occupies a very high position in the series, our palæontological data are too imperfect to allow of a detailed correlation. It is highly probable, however, that the beds about the level of the Kentish ironstone occupy the same position in the sequence as the "Upper Coral Rag" of Ringstead Bay, the "Kimmeridge Grit" of Damon[1]. Species of degenerate perisphinctoid ammonites which have not yet been grouped under a generic name are characteristic of this "Upper Coral Rag" in Dorset, where also occurs *Belemnites nitidus* Dollf. [*non* Phill.]. At Dover one of these ammonites occurred at the level of the ironstone (depth 600 feet), and the belemnite was found not far below[2].

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[1] H. B. Woodward. 'The Jurassic Rocks of Britain,' vol. v. (*Mem. Geol. Surv.*), 1895, pp. 84, 85.

[2] The ammonites here referred to, of the group of *A. involutus* Quenst., are distinct from the degenerate perisphinctoids referred to *Pictonia*. Dr. H. Salfeld of Göttingen is making a study of these forms and proposes to institute a new generic division for their reception.

These Upper Corallian Beds of Kent may be correlated in part with the Continental strata where, in some districts, an Astartian facies is developed. Thus they may be regarded as corresponding with a considerable portion of the Sequanian Series in the Boulonnais, in the restricted sense in which this term was applied by Pellat. It is not possible to say with certainty whether the beds equivalent to the uppermost Sequanian (Wirvigne Grit) fall at the base of our Virgula Beds or at the top of our Corallian, but a comparison of the faunas, so far as they are known, suggests the former correlation as the more probably correct one. At Le Havre a Pterocerian facies appears at a level which may correspond with the upper Astartian of other districts, and such local changes add to the difficulty of a precise correlation. But it is clear that some of the lowest "Kimmeridgian" beds of Le Havre correspond with the upper part of our Kentish Upper Corallian series. The beds about the level of the ironstone and above it may with little doubt be correlated with the Calcaires et Argiles à Trigonies of Dollfus at Cap de la Hève, for while it is true that the bivalve-fauna cited from the Calcaires à Trigonies[1] comprises a few species which seem to indicate correspondence with a slightly higher position in the Kentish series, yet greater weight must be attached to the occurrence of *Belemnites nitidus* and the ammonite at Dover, both of which constitute important links with the fauna of the Calcaires à Trigonies. It must not be forgotten that the lower part of the "Kimmeridge" strata of Le Havre represents in very condensed form a relatively extensive series of beds in Kent[2].

No doubt attaches to the character of the limestones which occupy the middle part of the Corallian Series both here and at Brabourne. At Dover these occur between a depth of 656 feet and 782 feet. Here are found the typical corals, the abundant gasteropods—including species of *Nerinea* and *Pseudomelania*, and *Cidaris florigemma*, as well as other forms which help to make up a characteristic "Coral Rag" fauna. The limestone is here divisible into two main masses, and although the general features of the fauna in each are the same, the upper limestone, which was more purely calcareous than the lower one, contained a much more rich and varied assemblage of gasteropods.

Owing to the variability in the time-incidence of the Coral Rag facies in different localities[3], it would be futile to attempt a very precise correlation of these limestone beds with the strata of other districts. For instance, in making a comparison with the series shown in the Boulonnais, we must be content to say that the character of the fauna suggests correlation with the beds of Coral Rag facies, containing *Thamnastraeae* and *Cidaris flori-*

[1] A. Dollfus. 'La Faune Kimméridienne du Cap de la Hève,' 1863, p. 5.

[2] For further particulars of the section near Le Havre and its fossils, see H. Douvillé. 'Note sur la partie moyenne du terrain jurassique dans le bassin de Paris et sur le terrain corallien en particulier,' *Bull. Soc. Géol. France*, ser. 3, vol. ix., 1881, p. 450. A. Tornquist. 'Die degenerierten Perisphinctiden des Kimmeridge von Le Havre,' *Abhandl. d. schweiz. pal. Gesellsch.*, vol. xxiii., 1896.

[3] Compare H. Douvillé. 'Note sur la partie moyenne du terrain jurassique dans le bassin de Paris,' *Bull. Soc. Géol. France*, ser. 3, vol. ix., 1881, p. 472.

gemma, at Brucdale and Mont des Boucards, which are overlain by the basal marly beds of Pellat's Sequanian[1]. It is scarcely necessary to emphasise how, in deposits of this kind, the facies-characteristics are so strong as to make the recognition of zonal characteristics a most difficult matter. It may be remarked that of the species commonly yielded by these Corallian limestones the zonal value of some is known to be very slight indeed, and in the case of many others their significance in this respect is really unknown. Unfortunately no remains of ammonites were found in this limestone series at Dover and Brabourne, and among the species of other classes much work remains to be done in order that some idea of their true vertical distribution within the Corallian Series may be obtained. Analogous difficulties are sufficiently familiar in Carboniferous palæontology. Yet, in view of the relative proximity of the Kentish localities to the outcrops near Boulogne, we think it not improbable that the change of facies from that of the coral limestones to that of the marly beds above may have taken place simultaneously, or nearly so, in the two districts.

The underlying beds, from a depth of 782 feet downwards, show lithological characters which unite them closely with the Oxford Clay. Although calcareous bands occur here and there, this lower division of the Corallian rocks consists here chiefly of clays, illustrating such a continuity of marine conditions at the boundary with the Upper Oxford Clay that no division-line can be selected on lithological grounds alone. Falling back upon the palæontological evidence, we are fortunately able to trace the succession of ammonite-faunas which gives the safest indications for a line of separation between the two formations. Here, however, in deciding upon the best dividing line in the light of previous work on the Oxfordian-Corallian rocks of this country, we meet with some difficulty owing to inconsistencies of classification. These are partly due, as Mr. Buckman has pointed out to us, to the fact that the Cordatus Beds, yielding *Cardioceras cordatum*, *C. quadratum* and allied forms, have been classed as Lower Corallian where calcareously developed, but when argillaceous they have sometimes been called Upper Oxford Clay. In fact, as is well known, the lithological boundary at the top of the Oxford Clay Series does not remain coincident with a palæontological boundary when traced from one part of the country to another; but of the two boundaries it is the lithological one which is the more inconstant, and the guiding ammonites are fortunately not found associated with one or the other lithological type alone, but occur with both. The confusion has unhappily been increased by the fact that species of *Quenstedtoceras*, occurring in a lower zone, have not infrequently been mistaken for *Cardioceras cordatum*. The definite succession of the ammonite-faunas is in reality well attested, and is borne out in the vertical sections with which we are now dealing, where no specimen of a *Cardioceras* was found mingled with *Quenstedtoceras* in the

[1] See J. F. Blake. 'On the Correlation of the Upper Jurassic Rocks of England with those of the Continent,' *Quart. Journ. Geol. Soc.*, vol. xxxvii., 1881, pp. 557–562.

uppermost Oxford Clay, and no example of *Quenstedtoceras* was seen to occur in the overlying beds which yielded *Cardioceras*. It must not be inferred from this that no overlapping in the occurrence of these two genera ever took place, but the facts before us certainly afford a sound working basis for the separation of the beds.

We have decided, therefore, to draw the division-line below the Cordatus Zone, and it may be estimated to fall at a depth of about 870 feet at Dover and 1,315 feet at Brabourne. Mr. Buckman observes that immediately below the beds with *Cardioceras cordatum* and above the zone of *Quenstedtoceras mariae*, that is, at the very base of the Corallian Series, according to his view, there occurs a distinct type of *Cardioceras*, which he has spoken of as "pre-*cordatus*," a form which probably has value as a stratigraphical guide. For reasons to be stated below, the presence of this could not be traced at Dover or at Brabourne, and our evidence, in fact, does not permit of any too narrow refinement in fixing the actual line of division between the Cordatus Beds and the underlying Mariae Beds.

(1.) *Fossils from the Upper Corallian Beds; depth,* 560 *feet to* 656 *feet.*

Depth in feet.	
[596—611]	Cidaris smithi *Wright* [spines]
[595]	„ sp. [spines]
[596—611]	Serpula tricarinata *J. de C. Sow.*
572	Ornithella sp.
[596—611]	Astarte sp.
[610—650]	Cyprina ?
[570—580]	Eopecten velatus (*Goldf.*) [Velopecten]
[575], [596—611], 620	Exogyra nana (*J. Sow.*)
572, [590]	„ sp.
[596—611]	Isocardia sp.
„	Lima sp.
[610—650]	Lucina sp.
[596—611], [611—650]	Modiola ?
[596—611]	Ostrea sp.
„	Pecten (Chlamys) fibrosus *J. Sow.*
„	Pleuromya *cf.* recurva (*Phill.*)
„	Protocardia sp.
„	Pteria sp. [smaller valve]
[585—590]	Trigonia voltzi *Ag.*
600	„ sp. [clavellate]
„	„ sp. [costate]
[596—611]	Bourguetia ?
„	Cerithium, 2 spp. [? nov.]
„	Perisphinctes sp. [*cf.* Am. convolutus *Quenst.*, pars]
[600]	Ammonite, gen. et sp. nov.
[610—650]	Belemnites nitidus *Dollf.* [non *Phill.*]
[596—611]	„ sp.

The list of fossils from above the ironstone at Dover differs from that obtained from the corresponding part of the section at Brabourne in the absence of *Pecten* cf. *kimmeridgensis* and of any specimen of *Exogyra* comparable with *E. virgula*; but, as already remarked, the collecting at Dover left much to be desired, and no significance can be attached to negative points such as this. The specimens obtained cannot be looked upon as at all

thoroughly representative of the fauna. A curious feature in these uppermost beds were the bands of peculiar soft pisolitic rock containing many obscurely preserved valves of *Ostrea* and *Exogyra* of small size. Some of these may belong to *Exogyra nana*.

At the horizon of the ironstone, at about 600 feet in depth, we find *Exogyra nana*, *Serpula tricarinata*, species of *Cerithium* and *Bourguetia?*, with spines of *Cidaris*, one of which seems inseparable from *C. smithi*. The fauna from the beds below the ironstone is very imperfectly represented in our collection owing to unfavourable conditions while the sinking was in this part of the section. At a depth of about 620 feet there occurs a hard impure limestone-band which shows molluscan borings (*Pholadidea?*) on its upper surface. The holes are filled in with loose rubbly material from the overlying beds, including specimens of *Exogyra nana*.

A species of *Ornithella* which was found to occur in the uppermost beds in loose pisolitic rock at about 30 feet above the ironstone is in some respects comparable with *O. hudlestoni* (Dav.). It differs, however, in having the beak-ridges more receding in character and the pseudo-area less well defined. Further, in *O. hudlestoni* there is a slight dorsal arching developed in the last growth-stage which is not shown in a specimen from Dover which has reached somewhat larger dimensions than those of the average adult individual of *O. hudlestoni*. This specimen measures 20 mm. in length, 15 mm. in breadth, and 10 mm. in thickness. The dorsal valve must be described as non-plicate, and any tendency there may be for the commissural line to rise at the frontal margin is most elusive, and if really shown is only of the slightest description.

Relationship to *O. lampas* (J. Sow.) is perhaps possible. According to the figures given by Davidson[1], the growth lines show that at dimensions corresponding with those of the shell from Dover the outline of the valve agrees fairly well, and is more oval and less narrowed anteriorly than in the fully-grown stage. But a narrow median longitudinal depression of the dorsal valve extending from the umbo characterises *O. lampas*, and this is not developed in the form which we are discussing.

In the beds below a depth of 610 feet were found examples of a belemnite which Mr. G. C. Crick refers to *Belemnites nitidus* Dollf. (*non* Phill.). Mr. Crick has kindly assisted us to compare a specimen with others of English origin in the British Museum, which he has determined as *B. nitidus*, and the agreement is complete. Dollfus obtained his specimens in the "Calcaire à Trigonies (argiles intercalées)" at Cap de la Hève, which lower division of his Kimmeridgian, as already remarked, must be correlated with part of the Astartian of other French localities, and may be considered to correspond also with some of these Upper Corallian Beds of our Kentish sections.

[1] T. Davidson. 'Mon. Brit. Foss. Brach.,' vol. iv,; Jur. Suppl., 1878, pl. xxii., fig. 3. *Palæontographical Society.*

(2.) *Fossils from the Corallian Limestones; depth, 656 feet to 782 feet.*

(a). The Upper Limestone; depth, 656 feet—709 feet.

Depth in feet.	
	Cladophyllia ?
	Isastraea explanata *Goldf.*
	Thamnastraea arachnoides (*Park.*)
	„ *cf.* concinna (*Goldf.*)
670	„ *cf.* dendroidea (*Lamour.*)
	„ sp.
	Thecosmilia annularis (*Flem.*)
	Cidaris florigemma *Phill.* [spines]
	„ smithi *Wright* [spines]
	Hemicidaris intermedia (*Flem.*) [spines]
	Pseudodiadema ? [test]
670—690	Terebratula bauhini *Etall.* [de Loriol's reading]
	„ maltonensis *Oppel*
	Astarte rhomboidalis *Phill.*
	Corbis sp.
	Cucullaea sp.
	Cyprina ? *cf.* corallina *d'Orb.*
	Grammatodon quadrisulcatus (*J. de C. Sow.*)
	Homomya tremula (*Bur.*)
	Isocardia bernardina ? *Etall.*
	Lithodomus sp.
	Lucina rotundata ? (*F. A. Roem.*)
	Myoconcha sp.
	Opis sp.
	Ostrea (Alectryonia) duriuscula *Phill.*
	„ „ gregaria *J. Sow.*
	„ „ solitaria ? *J. de C. Sow.*
	„ sp.
	Pecten (Chlamys) vimineus *J. de C. Sow.*
	„ (Camptonectes) virdunensis ? *Buv.*
	Perna sp.
	Pholadomya acuticostata *J. de C. Sow.*
	„ sp.
	Amberleya princeps ? (*F. A. Roem.*)
	Ataphrus erinus (*d'Orb.*) [Turbo (Monodonta)]
	Bourguetia striata (*J. Sow.*)
	Natica *cf.* arguta *Phill.*
	Nerinea tuberculosa *Defr.*
	„ sp. (A)
	„ sp. (B)
	„ spp. nov. ?
[690], [700—709]	„ spp. indet.
[690], [700—710]	Nerinella *cf.* calliope (*d'Orb.*)
	„ cyntbia ? (*d'Orb.*)
	„ elegans (*Thurm.*)
	Phaneroptyxis *cf.* fusiformis (*d'Orb.*)
	Pleurotomaria *cf.* reticulata (*J. Sow.*)
[700—710]	Pseudomelania heddingtonensis (*J. Sow.*)
	„ *cf.* langtonensis *Blake and Hudl.*
	Trochotoma tornatilis (*Phill.*)
	Trochus *cf.* aequalis *Buvign.*
	„ sp. nov.
	Turbo sp. nov.
	„ spp. indet.

With the exceptions noted above, all the fossils enumerated in this list were obtained from the limestone at about 690 feet in depth.

The remains of corals are for the most part poorly preserved, and the specimens are frequently replaced entirely by coarsely

crystalline calcite with the original structure largely or wholly obliterated. Sometimes the septal structure is shown in part of the coral while calcite crystals replace other parts. At a depth of about 670 feet were found examples of a *Thamnastraea* of slender cylindrical habit, which may possibly be new. It has some resemblance to *Th. dendroidea*, but our materials do not allow of a thorough comparison of characters.

The most striking characteristic of the Upper Limestone is the abundance of large shells of *Nerinea*, among which *N. tuberculosa* is the most conspicuous and evidently one of the most numerously represented. Specimens were also found which appear to belong to undescribed species. Thus, *Nerinea* sp. (A) of the above list bears much resemblance to *N. laufonensis* Thurm.[1], but is distinguished by the possession of a smaller number and different arrangement of the ornamenting spiral keels on the surface of the whorls. Another species, (B) of the list, has more nearly smooth whorls which show only very weak and evanescent spiral markings but stronger raised spiral lines on the base of the last whorl. We have not been able to identify this form. These specimens were seen on one occasion by the late Mr. W. H. Hudleston, but he did not recognise them and thought it probable that they might represent new species. Other specimens which may be provisionally referred to *Trochus* and *Turbo* also belong to new species, so far as we have been able to ascertain.

One of the most abundant lamellibranchs is a *Pecten* which was at first referred by us to *P. articulatus* of Goldfuss, the identity of which with Schlotheim's *P. articulatus* has been questioned by Seebach, de Loriol, and other authors. Our examples are possibly identical with d'Orbigny's *P subarticulatus*[2], but we believe they may with certainty be referred to *P. vimineus* J. de C. Sowerby. The identity of *P. subarticulatus* and *P. vimineus* was doubted by de Loriol, but the matter does not appear to us to have been finally settled. In any case the name *P. vimineus* was established at an earlier date. One of the specimens from Dover, a right valve, is peculiar in having a number of its ribs divided into two distinct portions by a median longitudinal furrow, but in other respects the characters are those of *P. vimineus*.

Specimens of *Terebratula* occur in the beds situated between 670 feet and 690 feet, and very abundantly at the latter depth. These are all uniplicate forms, showing a flat though well-raised median arching of the brachial valve and a linguiform anterior narrowing of the pedicle valve. There is some variation in the breadth of the individuals, but the majority are well characterised by the narrow, elevated and produced beak which stands up freely from the hinge-line and exposes the large and high deltidial plates. The degree in which the beak is thus produced and elevated is, however, somewhat variable, but in some individuals

[1] P. de Loriol. 'Études sur les Mollusques des Couches Coralligènes Inférieurs du Jura Bernois,' part 1, p. 46, pl. vi., figs. 10–15. *Mém. Soc. Pal. Suisse*, vol. xvi., 1889.

[2] P. de Loriol. 'Études sur les Mollusques des Couches Coralligènes Inférieurs du Jura Bernois,' part 4, p. 303, pl. xxxii, figs. 16, 17. *Mém Soc. Pal. Suisse*, vol. xix., 1892. *See also* Peron, 'Etudes paléont. sur les terr. du départ. de l'Yonne,' p. 217, pl. x., fig. 2. *Bull. Soc. Sci. Yonne*, tome lix., 1907.

these characters are very marked. One specimen which has rather greater breadth than the majority, is separable from the others by the very slight elevation of its beak, and this we believe to be *Terebratula maltonensis* Oppel. It agrees well in shape, in the nature of its beak, and in the swing of the lateral commissural line, with the example from Malton figured by Davidson to which Oppel made reference when introducing the name *maltonensis*, to denote a variety of *T. insignis* Schübler. We may speak of this as *T. maltonensis* since its relationship to Schübler's species is most doubtful.

The other specimens, which are well distinguished by their projecting beaks, show a similar stage of valve-plication, and a biplicate character is never reached. These very closely resemble the figures of specimens from the Corallian beds of the Swiss Jura referred by de Loriol to Etallon's *Terebratula bauhini*. Etallon's figure and description of his species were so insufficient that we must be content for the present to follow Douvillé's and de Loriol's application of the name. Several of our specimens agree very closely with examples illustrated by de Loriol in his memoir on the Corallian fossils of Valfin, and seem only to differ by the rather broader and less sharp lateral curve of the commissural line[1]. Some of our largest specimens, however, show even a closer resemblance to the figure of a fine individual given by Professor Douvillé[2]. Others, of smaller size, show a flatness of the valves and a degree of straightness of the beak which are characters of immaturity. In these the frontal plication is only incipient. One such immature specimen, kindly presented to us by Mr. W. J. Horner, agrees very closely indeed with the figure of an elongated individual from Saint-Ursanne in the Bernese Jura[3] Haas also has figured some shells from the Swiss Jura as *Terebratula* cf. *bauhini*[4], which show close resemblance to some of our adult examples.

(b). The Lower Limestone; depth, 709 feet—782 feet.

Depth in feet.	
758	Isastraea greenoughi *Edw. and Haime*
715—770	Thamnastraea sp.
734	Thecosmilia ?
Various levels	Corals, indeterminable
[730]	Crinoid columnals
709—770	Cidaris florigemma *Phill.* [spines]
760—770	„ smithi *Wright* [spines]
[750—770]	Glypticus hieroglyphicus (*Goldf.*) [test]
[740—770], [760]	Hemicidaris intermedia (*Flem.*) [test and spines]
709—770	„ sp. [spines]
[760]	Serpula tricarinata ? *J. de C. Sow.*
769	„ variabilis *J. de C. Sow.*

[1] P. de Loriol. 'Études sur les Mollusques des Couches Coralligènes de Valfin (Jura),' part 3, pl. xxxvii., fig. 12. *Mém. Soc. Pal. Suisse*, vol. xv., 1888.

[2] H. Douvillé. 'Sur quelques Brachiopodes du Terrain Jurassique.' *Bull. Soc. Sci. Hist. et Nat. Yonne*, tome ix., 1885, pl. i., fig. 7.

[3] P. de Loriol. 'Études sur les Mollusques des Couches Coralligènes Inférieurs du Jura Bernois,' part 4, pl. xxxvi., fig. 17. *Mém. Soc. Pal. Suisse*, vol. xix., 1892.

[4] H. J. Haas. 'Kritische Beiträge zur Kenntniss der jurassischen Brachiopodenfauna des schweizerischen Juragebirges,' part 3, pl. xxii., fig. 1. *Mém. Soc. Pal. Suisse*, vol. xx., 1893.

Depth in feet.	
[760]	Ornithella delmontana (*Oppel*)
770	Terebratula *cf.* maltonensis *Oppel*
734—770	,, sp.
[760]	Astarte ?
769	Exogyra sp.
[765]	Gervillia sp. nov. ?
[760]	Grammatodon *cf.* pectinatus (*Phill.*)
[770]	Gryphaea sp.
734—770	Lima (Plagiostoma) rigida (*J. Sow.*)
[760], 769	Lithodomus sp.
[709], 770	Ostrea (Alectryonia) gregaria *J. Sow.*
[715]	Pecten (Chlamys) inaequicostatus *Phill.*
[760], 769	,, ,, vimineus *J. de C. Sow.*
709, 769	,, spp.
768	Pholadomya paucicosta *F. A. Roem.* [large and numerous]
[760]	Trichites sp.
[765], [780]	Pseudomelania heddingtonensis (*J. Sow.*)
769	Crustacean

In these lower limestone beds, which are more impure than those above, there is a noticeable rarity of gasteropods; and this is in striking contrast to the abundance, particularly of *Nerinea* and allied forms, seen in the upper limestone. Here also the corals are replaced for the most part by crystalline calcite which makes their identification most difficult. At a depth of about 730 feet were seen specimens of *Thamnastraea* built up to form compact masses with all interstitial spaces filled with fine-grained calcite. At about the same depth the remains of *Hemicidaris* are relatively abundant. *Cidaris florigemma* was found throughout the limestone down to within a few feet of the base.

The numerous well-preserved examples of *Ornithella* which occurred at about 760 feet in depth may be referred to *O. delmontana* (Oppel), which does not appear to have been noticed before from any locality in this country. Fully grown individuals may measure upwards of 30 mm. in length and 20 mm. in breadth. The inflation is relatively strong in the median region and posteriorly to this, and becomes much less marked anteriorly. The greatest breadth occurs at about the middle of the shell or a little posteriorly to this, and from here the sides converge steadily towards the front. The short frontal margin is straight, and gives an aspect of anterior truncation. The beak is narrowed, well raised, and not strongly incurved, displaying well the relatively high deltidial plates. Sharp beak-ridges mark off a well defined pseudo-area.

The species has been well figured by Haas and by de Loriol[1], and our examples from Dover can be perfectly matched with some of the figures given by de Loriol. Another closely related Corallian form is *O. censoriensis* (Cott.)[2], which Prof. Douvillé considers to be doubtfully separable from *O. delmontana*.

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[1] H. J. Haas. 'Kritische Beiträge zur Kenntniss der jur. Brachiopodenfauna des schweiz. Jurageb.' Theil 1, p. 30, pl. ii., figs. 19–21. *Abhandl. der schweiz. pal. Gesellsch.*, vol. xvi., 1889.

P. de Loriol. 'Étude sur les Mollusques du Rauracien Infér. du Jura Bernois,' p. 85, pl. x., figs. 2–9. *Ibid.*, vol. xxi, 1894.

[2] H. Douvillé. 'Sur quelques Brachiopodes du Terrain Jurassique,' *Bull. Soc. Sci. Hist. et Nat. de l'Yonne*, ser. 3, vol. ix., 1886, p. 89, pl. iv., figs. 6, 7.

At about 770 feet in depth there were obtained specimens of a *Terebratula* which in some respects recall those we have referred to *T. bauhini*, in the upper limestone. While the stage of plication which has been attained is about the same in both forms, and biplication has not been reached, the character of the beak is a very different one. In these earlier examples the beak region is more inflated and the beak is well incurved and vertically truncated by the foramen, and it is bent down so closely upon the hinge-line as almost to conceal the shallow deltidial plates. There is a general resemblance to some of the specimens from the Corallian of Mont des Boucards figured by de Loriol under the collective specific name *T. insignis*[1], but our shells have a much deeper lateral ventrally directed curve of the commissure than is shown in the figures of the French examples. Although the character of the beak is in general agreement with that shown in *T. insignis*, so far as can be judged from Zieten's figure[2], yet we are unable to identify the Dover specimens with that species. Taking Zieten's figures as a guide, we have to do with a much smaller and more inflated form at Dover. There is closer resemblance, again, to *T. maltonensis* Oppel, but that species has a less strongly inflated and less markedly incurved beak and also a less strong curve of the lateral commissure. However, it is with *T. maltonensis* that the closest comparison can be made, and we may refer to these specimens as *T.* cf. *maltonensis*.

(3.) *Fossils from the Lower Corallian Beds; depth,* 782 *feet to* 870 *feet.*

(a). The upper part; depth, 782 feet—825 feet.

Depth in feet.	
[820—830]	Crinoid columnals
„	Rhynchonella sp.
[795]	Anatina (Cercomya) siliqua (*Ag.*)
800—825	Gryphaea dilatata *J. Sow.*
[810]	Modiola bipartita ? *J. Sow.*
810	Ostrea sp.
[810]	Pecten (Syncyclonema) demissus ? *Phill.*
„	„ (Chlamys) fibrosus ? *J. Sow.*
„	„ (Camptonectes) *aff.* lens *J. Sow.*
[780—800], 798	Pholadomya sp.
[780—800]	Thracia depressa (*J. de C. Sow.*)
[795]	*Cf.* Oechetoceras subclausum (*Oppel*) [or allied form]
[810]	Perisphinctes *cf.* torrensis *Choffat*

The fossils obtained from these beds are fewer in number than would have been the case had the material from this part of the section not been tipped within reach of the sea. Much of it was washed away before thorough collecting could be carried out. This was particularly the case with the rock from above 800 feet. In the clays between the depth of 782 feet and 793 feet large specimens of *Perisphinctes* were noted, but these could not be procured. Casts of *Trigonia* were also seen and a large univalve

[1] P. de Loriol and E. Pellat. 'Mon. paléont. et géol. des étages supér. de la Form. Jurass. des Environs de Boulogne-sur-mer,' part 2, pl. xxv., figs. 10–16. *Mém. Soc. Phys. et d'Hist. Nat. de Genève*, tome xxiv., 1875.

[2] C. H. v. Zieten. 'Die Versteinerungen Württembergs,' 1830–33, pl. xl., fig. 1.

resembling *Pseudomelania heddingtonensis*. In a dark clayey limestone below this, casts of a large *Nerinea* were seen but not collected. Specimens of *Pecten vimineus* and the spines of *Cidaris*, which were so abundant in the limestones above, appear to have been absent here. As in the case of the strata overlying the limestones, so in the underlying beds, we must expect to find a contrast between the fauna of these argillaceous sediments and that of the limestones, accompanying the lithological contrast.

The *Gryphaea*, which was numerously represented, is large and has widely expanded form. The inflation and incurvation of the umbo of the left valve is nearly always weak, this character standing in connection with the duration of attachment at the apex. Many specimens have a massive left valve with a relatively large, flat surface of attachment, and in these respects show a habit which is identical with that exhibited by many examples of *Gryphaea* which occur in the argillaceous development of the Lower Corallian Series in Bedfordshire and Huntingdonshire. The individuals from these particular beds at Dover have clean shells with the two valves frequently still in place, and not encrusted internally with *Serpula* and *Ostrea*. Although named *G. dilatata* in the list, these large shells illustrate a degenerate gryphaeate form which perhaps may not be identical. It is evident that the aberrant line of evolution from normal oysters, which is illustrated by these shells, occurs repeatedly and independently, and the number of such separate gryphaeate derivatives found in our Oxfordian and Corallian rocks still remains to be investigated. The name *G. dilatata* is therefore only used provisionally in these lists.

These beds immediately overlie those which undoubtedly belong to the Zone of *Cardioceras cordatum*, and they may possibly be equivalent, in their lower part at any rate, to some of the upper part of the Cordatus Beds elsewhere. Although no specimen of *Cardioceras* was found here above a depth of about 825 feet, yet, having regard to the circumstances under which the collecting had to be carried out, no positive conclusion can be drawn from that fact.

(b). The Cordatus Beds; depth, 825 feet—870 feet.

Depth in feet.	
830	Crinoid columnals
[860—870]	Serpula tricarinata *J. de C. Sow.*
830	Rhynchonella sp.
,,	Gervillia sp. [slender, long, and curved]
,,	Grammatodon sp. [nov.?; too short for G. concinna (*Phill.*)]
830, 835, [860—870]	Gryphæa dilatata *J. Sow.*
[860—870]	Ostrea sp.
830	Perna mytiloides ? *Lam.*
[825], 830	Pholadomya sp.
830	Pleuromya ?
,,	Unicardium *cf.* sulcatum *Leck.*
,,	Pleurotomaria ?
[825—830]	Aspidoceras *cf.* oegir (*Oppel*)
830	Cardioceras *cf.* cordatum (*J. Sow.*)
840	,, maltonense (*Young and Bird*)
[825]	,, quadratum (*J. Sow.*)
830	Peltoceras *cf.* constanti (*d'Orb.*)
[830]	Perisphinctes variocostatus ? (*Buckl.*)

There is no doubt whatever as to the palæontological horizon to which these beds must be referred, and the question is, how much of the underlying strata also must be included in the Zone of *Cardioceras cordatum*. Unfortunately, no fossils could be obtained from the clays between 840 feet and 860 feet in depth, because the materials from between 830 feet and 860 feet were shot into a disused shaft. Our specimen of *Cardioceras maltonense* from 840 feet was happily saved by the engineer in charge. The specimens secured from a depth of 870 feet to 890 feet show that the sinking had already passed into strata in which species of *Quenstedtoceras*, with the guide-fossil *Q. mariae*, were predominant. It thus happens that no evidence was obtained for the presence of beds with ammonites of the type termed "*pre-cordatus*" by Mr. Buckman, who thinks it probable that, were our data more complete, these beds would have been met with just below the Cordatus Beds, and that they may even have been represented by 20 feet or more of strata. According to Mr. Buckman's view, the palæontological dividing-line between the top of the Oxford Clay and the bottom of the Corallian would best be drawn at the base of these, had they been found.

There is fortunately one specimen, obtained from the clay just above a depth of 870 feet, which by analogy gives strong suggestion for a Lower Corallian age. This is a *Gryphaea* referred provisionally to *G. dilatata*, which differs from the examples of this "genus" from the true Oxford Clay in the manner mentioned above for certain Corallian forms. The shell (a left valve) is very massive and thick and shows the weak incurvation of the umbo and the relatively large area of attachment which was noted above. It shares these characters with the massive examples found in the lowest Corallian clayey beds of Bedfordshire and Huntingdonshire and in the Elsworth Rock. Moreover, it exhibits the further peculiarity that it is thickly encrusted, both outside and inside, with *Ostrea* and *Serpula*. This feature points to conditions of sedimentation different from those in which the *Gryphaeae* of the Oxford Clay below, or those noted above from higher beds, must have lived. Here we have an indication that for a time the rate of sedimentation was slow, and it is not improbable that current-action was the chief retarding factor which permitted the long exposure of these shells on the sea-floor. Precisely the same peculiarity has been observed in the case of the specimens of *Gryphaea* in the Elsworth Rock and Ampthill Clay (particularly in the Elsworth Rock) which are found to differ from those of the underlying Oxford Clay in this very feature of outward and inward encrustation by other organisms[1]. These facts afford a strong suggestion that the strata just above 870 feet may be correlated as the basal beds of the Corallian Series, and that the line of demarcation between these and the Mariae Beds should not be drawn at a higher level than 870 feet. The thick and massive character of the shells of *Gryphaea*, referred to above, might perhaps be thought to stand in connection with some physical cause, such as the turbulent conditions due to current-action of

[1] C. B. Wedd. 'On the Corallian Rocks of St. Ives (Huntingdonshire).' *Quart. Journ. Geol. Soc.*, vol. lvii., 1901, p. 83.

which we have a suggestion in the encrusted character of the valves. But similarly massive shells, showing also a modified habit of attachment when brought into comparison with the smaller specimens from a lower zone, for instance the large examples from between 800 feet and 835 feet at Dover, occur in Corallian beds and are not inwardly encrusted with other shells. In the Elsworth Rock and Ampthill Clay considerable diversity of type is shown by the large and massive oysters of gryphæate habit, and it seems only possible to regard these as representing offshoots from ostrean stocks, in which developmental degeneration is well illustrated. Significant features are the instability of form, with frequent departure in greater or less degree from the gryphæate habit, the modification in the nature and duration of the umbonal attachment, and the remarkably thick-walled and massive character of many of these shells. Analogous phenomena of degeneration in other molluscan genera and in brachiopods are known to stand in connection with definite developmental cycles, and have consequently a more intimate relationship to geological age than to special conditions of environment.

Oxford Clay.

No specimen of a *Cardioceras* was seen from a depth of 870 feet or below, but the beds here yielding *Quenstedtoceras*, by reason of the association of fossils they contain, may be confidently referred to the Mariae Zone. Below about 900 feet other ammonites were found, such as species of *Lunuloceras*, *Hecticoceras* and *Creniceras*, which characterise the fauna occuring in the Renggeri Zone of Continental authors. Mr. Buckman suggests that the beds between 900 feet and 945 feet may be ascribed to this zone, and without attempting, with our present evidence, to draw division lines too accurately, this may be regarded as an approximately correct assignment. No specimen of *Cosmoceras* was found at a depth above 945 feet, but the basal beds between 945 feet and 958 feet clearly belong to the Ornatus Zone, the lowest division of the Oxford Clay.

(1.) *Fossils from the Zone of* Quenstedtoceras mariae; *depth*, 870 *feet to about* 900 *feet.*

Depth in feet.	
[880]	Rhynchonella varians (*Schloth.*) [Davidson's reading]
,,	Grammatodon concinnus (*Phill.*)
872, [880], 895	Gryphaea sp. [dilatata *Auctt.*]
[880], [900]	Nuculana phillipsi (*Morr.*)
[880], [885]	Pinna mitis ? *Phill.* [abundant]
[900]	Trigonia *cf.* perlata *Ag.*
[870—880]	Perisphinctes *cf.* curvicosta (*Oppel*)
[885]	,, *cf.* sulciferus (*Oppel*)
[880]	Quenstedtoceras lamberti (*J. Sow.*)
,,	,, leachi (*J. Sow.*)
[870—880], [880]	,, macrum (*Quenst.*)
[880]	,, *cf.* ,, mariæ (*d'Orb.*)
,,	,, ,, *cf.* omphaloides (*J. Sow.*)
[900]	Belemnites sp.
[880]	Mecocheirus ?

The fossils were distributed here chiefly in bands, and were not found with equal abundance scattered throughout the clay. Specimens of *Pinna*, though crushed and imperfectly preserved, were relatively abundant hereabouts, and their remains were often partly pyritized. In the case of the ammonites, many specimens were pyritized while others were not.

The *Gryphaea* is here of less massive type than the one noted from somewhat higher beds, and is also distinguished by a much smaller surface of umbonal attachment and by not being encrusted with *Ostrea* and *Serpula*. As already noted, this is a distinction which separates the *Gryphaeae* of the uppermost Oxford Clay from many of those in the lowest Corallian beds in Bedfordshire and Huntingdonshire in which a more prolonged adnascent stage is associated with a massive habit.

(2.) *Fossils from the Zone of* Creniceras renggeri; *depth, from about* 900 *feet to* 945 *feet.*

Depth in feet.	
923	Lignite
„	Terebratula sp.
„	Arca sp.
[910], 923	Astarte sp.
924, [930]	Grammatodon sp.
[940]	Gryphaea sp.
920	Modiola sp.
[915]	Nucula sp.
[910]	Nuculana phillipsi (*Morr.*)
[930]	„ sp.
[910]	Pecten (Syncyclonema) demissus *Phill.*
[915], 924	Pinna mitis *Phill.*
[915], 940	Pteria ?
920	Thracia sp.
„	Trigonia sp. [clavellate]
[910], [915]	Alaria trifida (*Phill.*)
920	Pleurotomaria reticulata ? (*J. Sow.*)
[930]	Creniceras crenatum (*Brug.*)
920	Hecticoceras *cf.* punctatum (*Stahl*)
[900—920], 920	Lunuloceras ? laevigatum (*Rein.*) [non *Sow.*]
[915]	? Lunuloceras pompeckji *Par. and Bon.*
[940]	Lunuloceras *cf.* socini (*Noetl.*)
[915], 920, [924—940]	„ sp.
[924—940]	Peltoceras annulare (*Rein.*)
[900—920], 920, 924, [930]	Perisphinctes curvicosta (*Oppel*)
[900—920]	„ gleimi ? (*Steinm.*) *Par. and Bon.*
920	„ steinmanni ? *Par. and Bon.*
920	Quenstedtoceras goliathus (*d'Orb.*)
[910], [924—940]	„ lamberti (*J. Sow.*)
925, [924—940]	„ leachi (*J. Sow.*)
[915]	„ *cf.* „
[924—940], [940]	„ macrum (*Quenst.*)
[900—920], [915], 923	„ „ ?
920, [940]	„ omphaloides (*J. Sow.*)
[942]	„ *cf.* placenta (*Leck.*)
[900—920]	Sowerbyceras ?
[925], [924—940]	Taramelliceras sp. [*cf.* Am. flexuosus inermis *Quenst.*]
923, [930]	Belemnites hastatus *Blainv.*
[915], 920	„ sp.
[915]	Mecocheirus ?

In the upper part, above 920 feet in depth, fossils were sporadic in occurrence and not abundant. *Quenstedtoceras* became less numerously represented by individuals, and forms ascribed provisionally to *Lunuloceras* in the above list began to make their appearance, as we pass downwards. Below 920 feet, these, together with *Hecticoceras* and *Creniceras*, give a very distinctive facies to the cephalopod-fauna. At about 923 feet there occurred a hard band of greenish sandy calcareous rock containing pyritized ammonites and many specimens of *Terebratula* preserved with the shells very dark or black in colour, all, however, badly crushed.

(3.) *Fossils from the Ornatus Zone; depth* 945 *feet to* 958 *feet.*

Rhynchonella varians (*Schloth.*) [Davidson's reading]
Terebratula sp.
Astarte carinata? *Phill.*
,, sp. [outline like that of A. ovata W. *Smith*]
Cucullaea *sf.* subtetragona (*Morr.*)
,, sp. (A).
Gervillia aviculoides (*J. Sow.*)
Grammatodon sp. (A)
Gryphaea sp. [basement bed]
,, sp. (A) [basement bed]
Lima (Plagiostoma) rigida (*J. Sow.*)
,, sp.
Lucina?
Modiola?
Ostrea sp.
Pecten (Chlamys) fibrosus *J. Sow.*
,, (Syncyclonema) demissus *Phill.*
Pleuromya *cf.* recurva (*Phill.*) [basement bed]
Pseudomonotis sp. [basement bed]
Trigonia *cf.* complanata *Lyc.*
Pleurotomaria? [cast] [basement bed]
Cosmoceras castor (*Rein.*)
,, duncani (*J. Sow.*)
Belemnites oweni *Pratt* [basement bed]

Except for the lowest foot or so of these beds, the Ornatus Zone is here represented by hard grey clay containing numerous fossils. Conspicuous in point of numbers are small specimens of *Cucullaea* and *Grammatodon* which are preserved for the most part as casts and moulds of a marked brownish colour. The same forms, preserved in like manner, were found to occur numerously in the lowest 60 feet of the Oxford Clay at Brabourne, and they are briefly discussed in the notes appended to the list of fossils from the Ornatus Beds at that locality. Their presence was not detected in the shelly basement bed at Dover, but from the nature of that bed it is quite possible that they might have escaped observation.

This basement bed, about a foot in thickness, is of darker colour than the overlying clay and contains ferruginous oolite grains. It is densely crowded with fossils, chiefly lamellibranchs; but many fragments of belemnites were also found in it. The fossils are much crushed together, and few could be extracted in a fit state for identification. The most conspicuous lamellibranch was a *Gryphaea* reminiscent of *G. dilatata*, and so far as

could be ascertained this possessed no marked groove and posterior alar expansion in the left valve, the distinctive character of the large *Gryphaea* in the underlying Kellaways Beds. One specimen of a *Gryphaea* was obtained which appears to agree in its characters with the form named *Gryphaea sp.* (A), which was found in the Kellaways Beds both here and at Brabourne. This species is discussed below in the notes appended to the list of Kellaways fossils.

In the list given above, those species marked "basement bed" were found only in that bed. Some of the other lamellibranchs, seen in the overlying clay, occurred in the bottom bed also, but no example of *Cosmoceras* was met with so low down; that, however, is a circumstance from which, alone, it would be unsafe to infer the Pre-ornatus age of this bed.

It may here be mentioned that at the sinking now in progress at Tilmanstone the Hastings Sands were found to rest directly upon a clay which proved to be the basement of the Oxford Clay. Fossils from this bed placed before us by Dr. Malcolm Burr included *Gryphaea sp.* (A) and *Belemnites oweni*. Although a reference to the Jurassic rocks met with at Tilmanstone does not fall within the intended scope of this memoir, it is of interest to note very briefly some of the information which has recently been put before us respecting the beds passed through there between the Hastings Sands and the Great Oolite Series. By this additional evidence the scheme of subdivisions previously adopted by us for this part of the series at Dover and Brabourne becomes materially supported.

Strata between the Oxford Clay and the Lias.

(1.) *Fossils from the Kellaways Rock; depth,* 958 *feet to* 993 *feet.*

Depth in feet.	
[990]	Lignitized wood
[978]	Serpula ?
,,	Rhynchonella varians (*Schloth.*)
,,	Eopecten sp. [Velopecten]
[962—976], [978]	Gryphaea bilobata *J. de C. Sow.*
,, ,,	,, sp. (A)
959—962, ,,	Pecten (Syncyclonema) demissus *Phill.*
,, ,,	Pseudomonotis sp. nov.
986—988	,, sp.
986—988, [990]	Pteria (Oxytoma) inequivalvis (*J. Sow.*)
986—988	Trigonia sp. [clavellate]
[978]	Belemnites sp. [fragments of a large form]

In the uppermost four feet of the beds here ascribed to the Kellaways Rock, examples of a *Pseudomonotis* occur very abundantly, and except a *Pecten*, no associated fossils were seen. The specimens of *Pseudomonotis* are well characterised by the relatively great height in relation to length, and by the strong inflation of the left valves, as well as by the small degree of obliquity in the figure of the valves. A typical specimen measures 19 mm. in length and 21 mm. in greatest height, but examples also occur showing relatively greater length, while, in regard to size, the above dimensions are sometimes exceeded. The fine radial ribs show little or nothing in the nature of

asperities, and finer ribs become intercalated at various points on the surface between the coarser ones. This form appears to belong to an undescribed species. Those shells of similar age with which it may be most closely compared, for instance examples from Chippenham, have been commonly referred to *Pseudomonotis ovalis* (Phill.), but doubtless incorrectly. Specimens from Chippenham agree very closely with those from Dover, but tend to have a slightly greater obliquity in the figure of the left valve. Allowing something for variation, they may perhaps be identical. *Pseudomonotis ovalis*, on the other hand, a Corallian form, is well distinguished by a less degree of convexity of the left valve, by the more oblique figure of that valve, and by a marked cancellation on the surface caused by the intercrossing of concentric growth-ridges with the radial ribs. The presence of this last character might be thought to depend somewhat upon the state of preservation, but the specimens from Chippenham have the surface very well preserved, and in these the cancellation does not form a feature.

In the beds below this, the commonest fossil is the characteristic *Gryphaea bilobata*, which was found also at Brabourne at the corresponding horizon. It is represented by large individuals showing well the sulcus and wide posterior alar expansion of the left valve. It occurs abundantly in the greenish loamy sand and is accompanied by specimens of *Gryphaea* belonging to another form, probably an undescribed species, referred to as species (A) in the above list. The available examples are of considerably smaller size than the commoner *G. bilobata*, and are left valves having a very small area of attachment and a degree of convexity resembling that of *G. bilobata*; but they appear to lack the marked sulcus and posterior alar expansion which characterise that species, and they have a relatively more convex and less expanded form than the so-called *G. dilatata* of the Oxford Clay. Specimens agreeing with these in all particulars are preserved in the Museum of Practical Geology, labelled "Oxford Clay, near Cannings Court." They may perhaps have come from some spot so far to the north or north-west of this Dorset locality as to fall within the lowest (Kellaways) beds in the tract of country there mapped as Oxford Clay.

In the beds just above the depth of 980 feet, in which *Gryphaea* was found to be so abundant, many fragments of belemnites were noted, some of large size; but it was not possible to collect examples sufficiently well preserved for the purposes of identification. In the material from below this depth, however, down to the base, no traces of belemnites or of *Gryphaea* were seen, and the fossil most numerously represented was *Pteria* (*Oxytoma*) *inequivalvis*, with which were associated a few imperfect valves of a *Pseudomonotis* and a clavellate *Trigonia*.

Kellaways Beds have also been passed through in the sinking at Tilmanstone, No. 1 Pit, where, in like manner, the greenish loamy sand yielded numerous specimens of *Gryphaea bilobata*. Associated with these at a depth of 1,052 feet occurred *Sigaloceras calloviense* (J. Sow.), a specimen of which was submitted to us by Dr. Malcolm Burr.

(2.) *Fossils from the Cornbrash and Forest Marble.*

(a). Cornbrash; depth, 993 feet to 1,006 feet.

Astarte fimbriata *Lycett*
Grammatodon sp.
Modiola lonsdalei? *Morr. and Lyc.*
Pholadomya phillipsi *Lycett*
Pseudomonotis echinatus (*J. Sow.*)

No fossils could be obtained from the lowest five feet.

From the sandy clay which we may provisionally regard as the equivalent of the Cornbrash, it was only possible to secure the above representatives of the fauna, although when the collection was made it was seen that fossils occurred plentifully. The wet condition of the material, which was washed by heavy rains directly after being tipped at the surface, made it very difficult to secure specimens worth bringing away. The most abundant fossils noted were bivalves such as the above, together with *Pleuromya*, *Pecten* (*Syncyclonema*) and *Pteria* (*Oxytoma*). No traces of ammonites or belemnites were seen although much of the rock was carefully examined. *Pseudomonotis* was found to be common, and also a little strongly-ribbed *Astarte*, which we think may be identified with *A. fimbriata*, a species which, if not of familiar occurrence in the Cornbrash, is known from the Forest Marble.

The specimens of *Pseudomonotis echinatus* are preserved with the test undestroyed, and in view of the variation which is shown by individuals of this species, the identification may be regarded as correct. The variation to which we allude is chiefly expressed in the degree of inflation of the left valve and the coarseness of the ribbing. No doubt the degree in which the fine imbricating lamellar ridges are raised to form asperities on the ribs may be partly dependent upon local circumstances of environment. Most of the specimens seen at Dover are characterised by a relatively weak inflation of the left valve and fineness of the ribbing.

Large valves of *Pholadomya* were the most readily noticeable fossils in the material from these beds, but they were found to be without the test and had all suffered in greater or less degree from crushing. Careful comparison with Lycett's type leaves little or no doubt that they may be identified with *Ph. phillipsi*, a species which is characteristic of the Cornbrash.

The sinking at Tilmanstone Colliery, No. 1 Pit, passed through the Cornbrash at a depth of about 1,090 feet. Some fossils from that depth submitted to us by the East Kent Colliery Co., Ltd., included *Holectypus depressus* (Leske), *Rhynchonella major* Desl. [*non.* Sow.], *Microthyris lagenalis* (Schloth.), *Ornithella obovata* (J. Sow.) and *Terebratula intermedia* J. Sow.

(b). Forest Marble; depth, 1,006 feet to 1,024 feet.

In the thin limestone and the underlying series of claystones which we have provisionally assigned to the Forest Marble, fossils were found to be very scarce and poorly preserved. In the limestone bed at the top, only a single small valve of *Pteria* was

observed. Below 1,010 feet some obscure remains of lamellibranchs, including *Pleuromya*, were noted, and in the claystone below 1,016 feet the only fossils recognised amongst the traces of lamellibranchs were *Modiola* and *Astarte fimbriata* Lycett, which is a common species in the Forest Marble elsewhere. Here occurred also isolated "ganoid" fish-scales and specks of lignite. At a depth of about 1,820 feet, a thin dark band of clayey oolitic limestone contained abundant lignite as well as pyritized moulds and casts of lamellibranchs obscurely preserved. The fragments of lignite here attained a length of two or three feet and showed woody structure.

(3.) *Fossils from the Great Oolite Limestones and the underlying sandy beds.*

Throughout this part of the series fossils were found to be relatively scarce, and considering the large amount of rock brought to the surface in the course of shaft-sinking, the palæontological information obtained during several visits proved disappointingly small. No remains of cephalopods or gasteropods were found, and it is fortunate that the lamellibranchs and brachiopods obtained include examples of species which are of use in determining the position in the sequence.

(a). The Limestone Series; depth, 1024 feet to 1060 feet.

Depth in feet.	
1,040—1,043	Thamnastraea ?
„	Acrosalenia ? [smooth spines]
„	Serpula sp.
„	Rhynchonella *aff.* obsoleta (*J. Sow.*)
„ and 1,060	„ sp.
„	Terebratula bathonica (*S. S. Buckm.*)
„ and 1,060	„ sp.
„	Lima sp.
„	Myoconcha sp.
„ and 1,060	Ostrea sp.
„	Pecten (Chlamys) vagans *J. de C. Sow.*
„	„ (Camptonectes) *cf.* annulatus *J. de C. Sow.*
„	Pleuromya ?

No fossils were found in the highest 15 feet of limestones, but in the grey impure limestone between the depths 1,040 feet and 1,045 feet brachiopods and lamellibranchs occurred numerously, though they were not well preserved and many were crushed. Amongst them, *Terebratula bathonica* is an important guide-fossil which fixes beyond doubt the Bathonian age. This is one of the forms figured by Davidson[1] as *Terebratula maxillata* J. de C. Sow., but Mr. S. S. Buckman has shown that it is distinct from the true *T. maxillata*, and he has therefore renamed it[2]. He remarks that "it is characteristic and fairly abundant in the Great Oolite."

[1] T. Davidson. 'Mon. Brit. Foss. Brach.,' vol. i., part 3, 1851, pl. ix., fig. 3 only. *Palæontograph. Society.*

[2] S. S. Buckman. 'Brachiopod Nomenclature,' *Ann. Mag. Nat. Hist.*, ser. 7, vol. xviii., 1906, p. 322.

Mr. Buckman has proposed the adoption of Phillips's generic name *Epithyris* for the group of *Terebratula maxillata*, as a further step towards a more precise classification of the Jurassic terebratulids.

The *Rhynchonellae* obtained here were mostly immature specimens showing characters which appear to ally them with *R. obsoleta*.

In the underlying beds the remains of fossils are very scarce, but in a sandy limestone at 1,060 feet in depth there was a thin parting with the crowded shells of *Ostrea, Terebratula* and *Rhynchonella*, many of which are crushed and flattened.

(b). The Sandy Series ; depth, 1,060 feet to 1,083 feet.

Depth in feet.	
1,080—1,083	Coral [indet.]
[1,068]	Serpula sp.
[1,067—1,076]	Rhynchonella *aff.* obsoleta (*J. Sow.*)
,,	,, *cf.* hopkinsi *Dav.*
,,	,, *cf.* rostrata (*J. de C. Sow.*)
,,	,, *cf.* royeriana *d'Orb.*
,, and 1,080	,, sp.
1,080—1,083	Terebratula bathonica (*S. S. Buckman*)
[1,067—1,076], 1,080—1,083	,, sp.
[1,067—1,076]	Gervillia subcylindrica *Morr. and Lyc.*
,,	Grammatodon hirsonensis ? (*d'Orb.*)
,,	Gresslya ?
1,080—1,083	Lima (Plagiostoma) bellula *Morr. and Lyc.* [non *d'Orb.*]
[1,067—1,076]	Modiola sp.
[1,067—1,076], 1,080—1,083	Ostrea sowerbyi *Morr. and Lyc.*
,, and 1,080	,, sp.
[1,067—1,076]	Pecten (Chlamys) vagans *J. de C. Sow.*
1,080—1,083	,, (Camptonectes) *aff.* lens *J. Sow.*
,,	Pholadomya deltoidea (*J. Sow.*)
[1,067—1,076]	Placunopsis socialis *Morr. and Lyc.*
[1,067—1,076], 1,080—1,083	Trigonia sp. [costate]

The uppermost 10 feet of these calcareous sands and sandy limestones yielded only occasional traces of organic remains, such as *Ostrea* and *Serpula*, but below a depth of 1,070 feet a more shelly bed containing numerous badly preserved lamellibranchs and brachiopods was found to occur. All those specimens which it is possible to identify belong to Great Oolite species. Mr. Buckman has seen a few of the *Rhynchonellae*, and he suggests the nearest comparison with *R. rostrata, R. hopkinsi* and *R. royeriana*. Regarding *R. rostrata*, he says that this form is not uncommon in the Bath district at the top of the Great Oolite, and he also informs us that *R. hopkinsi* occurs in the beds just below those in which *Terebratula bathonica* has its maximum. In the lowest few feet, again, in the grey sandy beds just below 1,080 feet, were seen many fossils in a broken and badly preserved state, including *Terebratula bathonica, Ostrea sowerbyi, Lima bellula* and *Pholadomya deltoidea*, amongst other forms.

The palæontological evidence thus shows that at a depth of 1,083 feet the Great Oolite had not been passed through, and below this depth our knowledge is gathered entirely from the examination of the cores of a 10-inch advance-boring which was put down from the bottom of the shaft. No recognisable fossils were found in these lowest 37 feet of beds above the Lias, and there

is therefore nothing to show whether the Inferior Oolite is represented at this locality or whether strata of Great Oolite age rest directly upon the Lias. It will be seen below that the uppermost bed of Lias preserved here belongs to a low zonal position in the Toarcian, so there is every indication that the hiatus between the Liassic and Oolitic Series at Dover is a very considerable one.

Lias.

Our knowledge of the palæontology of the Lias at Dover is relatively scanty, and is derived merely from the examination of the cores of the 10-inch advance-boring which was put down when the base of the shaft was still in the Great Oolite Series. The shaft itself was subsequently sunk through these beds by a method which precluded the collecting of fossils. Only three markedly fossiliferous horizons were revealed by the cores, a bed of grey clay about 5 feet thick at the top, a sandy calcareous clay 1½ feet thick about the middle, and the basal grey clay of 4 feet in thickness resting directly upon Coal Measures.

In the following notes the names of the zones mentioned are employed in the broader sense as used by Mr. H. B. Woodward[1].

(1.) *Fossils from the Upper Lias* (*Serpentinus Zone*); *depth*, 1,120 *feet to* 1,125 *feet*.

Orbiculoidea reflexa (*J. de C. Sow.*)
Astarte sp. [small, coarsely ribbed]
Corbula sp.
Grammatodon sp.
Ostrea sp.
Pleuromya sp.
Cerithium?
Dactylioceras annulatum? (*J. Sow.*)
,, delicatum (*Simpson*)

In this grey clay at the top of the series fossils occur very numerously and are densely crowded together. The commonest form is a small oyster which has not been identified. It has an acuminate form, narrowed and prolonged in the umbonal direction, and is often slightly crescentic in shape. It somewhat resembles *O. sowerbyi* Morr. and Lyc., from the Great Oolite Series, but lacks the rugose character of this. Specimens measure about 20 mm. from the umbo to the opposite border, and about 15 mm., or sometimes less, in the greatest diameter at right angles to this. Associated with these are many small lamellibranchs, one of which, referred provisionally to *Corbula*, occurs very abundantly. This shell has slightly greater length than height, and its umbones are sub-central. The valves are posteriorly produced and truncated, and a flattened posterior area is marked off somewhat sharply by a carina running from the umbo to the postero-ventral angle of the valve. The surface is ornamented by numerous delicate concentric linear ribs which pass over to the posterior area. The average length of this little shell is 5 or 6 mm.

[1] H. B. Woodward. 'The Jurassic Rocks of Britain,' vol. iii. (*Mem. Geol. Surv.*), 1893, p. 34 ["General Grouping"].

The above two species, together with specimens of a small *Grammatodon*, too imperfectly preserved for identification, and *Orbiculoidea reflexa*, form in themselves a characteristic association of fossils by which this bed can be recognised: but more important are the finely-ribbed specimens of *Dactylioceras* which were fortunately secured. Mr. Buckman has referred these to species which indicate a horizon within the Serpentinus Zone, and perhaps in the lower part of the zone; in the actual words of his report, "Falcifer Zone or just below." It is thus seen that the Upper Lias is very incompletely represented at Dover, and the recognition that this uppermost clay belongs to a horizon so little above that of the Spinatus Zone, gives additional justification for believing the underlying beds to represent the Middle Lias.

It is an interesting fact that a bed corresponding precisely with the uppermost band of Lias clay at Dover was met with in the boring at Ropersole, near Barham, at a depth of 1,545 feet. Both the lithological and palæontological agreement is complete, and a small hand-specimen in the collection of the Geological Survey contains a finely-ribbed example of *Dactylioceras* associated with the brachiopod and lamellibranchs mentioned above.

(2.) *Fossils from the Middle Lias; depth, between* 1,126 *feet and about* 1,142 *feet.*

Depth in feet.	
1,134—1,136	Rhynchonella sp.
,,	Belemnites breviformis *Voltz*
,,	,, sp.

The core from this thin belemnite-bed yielded very scanty remains, but several examples of belemnites, apparently belonging to more than one species, occurred in a single hand-specimen. Associated with these are imperfect specimens of *Rhynchonella*, seemingly too ill-preserved for definite identification, but it is possible that some of them may represent *R. tetrahedra* (J. Sow.). One of the belemnites obtained shows some signs of rolling, and it should be mentioned that at a depth of about two feet below this bed there occurs a thin band also yielding some belemnite remains, which is largely made up of small, rolled shell fragments, too finely comminuted even for generic identification. *Belemnites breviformis* is elsewhere a characteristic form of the Spinatus Zone.

(3.) *Fossils from the Lower Lias* (*Capricornus Zone*); *depth,* 1,142 *feet to* 1,158 *feet.*

Depth in feet.	
1,154—1,158	Traces of plants
,,	*Rhynchonella *cf.* calcicosta (*Quenst.*)
,,	Astarte *cf.* irregularis *Terquem*
,,	*Grammatodon intermedius (*Simpson*)
,,	*Nuculana sp. [with long rostrum]
,,	*Protocardia sp.
,,	Lamellibranchs, indet.
,,	*Liparoceras maculatum (*Young and Bird*)

* The names marked with an asterisk are those of specimens in Mr. Joh Gerrard's collection.

The lowest four feet of Lias yielded only a small assemblage of fossils, and the specimens in the collection of the Geological Survey comprise nothing which gives indication of the exact zonal position. Fortunately this deficiency has been made good through the kindness of Mr. John Gerrard, H.M. Inspector of Mines, whose small collection from this horizon, freely placed at our disposal, contains an ammonite which Mr. Buckman refers to *Liparoceras maculatum* (Young and Bird). This points definitely to a position in the upper part of the Capricornus Zone, the highest zone of the Lower Lias. It thus becomes apparent that the greater part of the Lower Lias, from the Planorbis Zone up to the Jamesoni Zone, and probably the lower part of the Capricornus Zone, is absent at Dover. It will be seen that the Capricornus Clay, with the same ammonite, was met with also in the boring at Brabourne, where, however, it was much more thickly developed and was underlain by strata representing the Jamesoni Zone, and possibly even by still older beds.

Amongst the few lamellibranchs obtained from this lowest bed at Dover are two which were also found in the corresponding horizon at Brabourne, the shells we have named *Astarte* cf. *irregularis* Terq. and *Grammatodon intermedius* (Simps.). The latter name is given with some little hesitation, and is used in accordance with Tate's interpretation, but the Kentish specimens agree well with some of the forms, such as Tate's *Cucullaea grangeri*, which were finally regarded by that author to be identical with Simpson's species. Mr. Gerrard's collection contains a good specimen which measures 15 mm. in length and 10 mm. in greatest height, and its delicate radial linear ornaments, which intercross with concentric striæ, are distributed evenly over all parts of the shell.

Another species which may perhaps prove of help in characterising this imperfectly known lamellibranch-fauna is a representative of the genus *Nuculana*. A specimen was seen but could not be brought away, and there is another in Mr. J. Gerrard's collection, in the form of an external mould with some thin remnant of the shell adhering. The preservation is such that no trace of surface sculpture can be observed. The frontal outline forms a sweeping curve, merging into the upper and lower borders, and the umbo is well removed from the anterior extremity and is recurved. Posteriorly, the valve is produced to form a long, attenuated rostrum. In shape the shell closely resembles *Nuculana texturata* (Terq. and Piette)[1] and *N. tenuistriata* (Piette)[2], described from much lower horizons in the Lias of Eastern France. Comparable also is *Nuculana graphica* (Tate)[3], which occurs in the Capricornus Zone and also, according to Tate, in the Middle Lias. It is not possible, however, with the single imperfect specimen available to attempt a specific identification.

[1] O. Terquem and E. Piette. 'Le Lias Inférieur de l'est de la France,' *Mém. Soc. Géol. France*, ser. 2, vol. viii., 1868, p. 89, pl. xi., figs. 5–7.
[2] *Ibid.*, p. 89, pl. xi., figs. 8, 9.
[3] R. Tate and J. F. Blake. 'The Yorkshire Lias,' 1876, p. 386, pl. xiii., fig. 4.

CHAPTER X.

THE BRABOURNE BORING.

Lower Greensand.

The only organic remains collected from the cores representing the strata between the Gault Clay and the Weald Clay in this boring consisted of a few remains of molluscs and brachiopods, and these were all obtained from a light green loam ascribed to the Sandgate Beds at a depth of 240 feet to 250 feet from the surface. They comprise nothing that is of value for a narrow zonal correlation. *Pecten (Neithia) morrisi*, which is closely related to *P. (Neithia) quinquecostatus* J. Sow., occurs in the Hythe Beds and Atherfield Beds of other localities. The same must be said of *Gervillia forbesiana*, but this species has a wide upward range. The small fragment of an ammonite or ammonitoid is so very imperfect that no conclusions can be drawn from it, and it might possibly even be the remnant of a *Crioceras*.

Fossils from the Sandgate Beds.

Terebratula sp.
Exogyra sp.
Gervillia forbesiana *d'Orb.*
Nuculana sp.
Ostrea (Alectryonia) sp. [fragment]
Pecten (Neithia) morrisi (*Pict. and Ren.*)
Fragment of an ammonite

Wealden Series.

Very few fossils were recovered from the Weald Clay of Brabourne, and these came principally from the upper beds. They are of little value for comparative purposes, and comprise nothing that calls for special remark.

Fossils from the Weald Clay; depth, 303 *feet to* 412 *feet.*

Depth in feet.	
312, [300—400]	Cyrena sp.
315	Unio sp.
312—315	Viviparus sp.
311, 315, [300—400]	Cypridea valdensis (*J. de C. Sow.*)
312, [300—400]	Metacypris fittoni (*Mant.*)
311	Fish remains

The fauna of the Hastings Beds of this locality is likewise most imperfectly known, and the only specimens at hand are *Cyrena* and indeterminable lamellibranch-fragments from a depth of 463 feet, *Darwinula leguminella* (Forbes) from the same depth, and fragmentary fish-remains from betwen 460 feet and 475 feet. Remnants of wood and lignite were found between this depth and the base, and fragmentary plant-remains occurred at 505 feet, 532 feet and 567 feet. *Onychiopsis mantelli* (Brongn.) has been identified from a bed situated at 509 feet in depth.

Purbeck Beds.

Below the Hastings Beds the uppermost 12 feet of strata provisionally classified with the Purbeck Beds yielded fragments of

shells in their lower part. Some of these were seen by Mr. E. T. Newton, who thought them most probably to represent fresh-water forms. Beneath this, however—that is to say, below a depth of 624 feet—the scanty remnants of the fauna which were contained in the cores included not only several genera of fresh-water facies such as *Unio*, *Viviparus* and *Valvata*, but also specimens of *Protocardia* and *Corbula*, which indicate brackish water conditions.

The palæontological material furnished by the cores from this part of the section is very sparse, and it does not enable us to make any detailed correlation with the Purbeck rocks of other regions; but the presence of *Protocardia purbeckensis* and *Corbula alata* below a depth of 630 feet suggests that this part of the series may be best compared with the Corbula Beds and Pecten Beds of the Middle Purbeck in Dorset.

Fossils from the Purbeck Beds; depth, 612 *feet to* 680 *feet.*

Depth in feet.	
[624—627], 631 [641—651], 674	Plant remains
[612—624]	Cyrena sp. [G. W. L.]
[641—651]	Corbula alata *J. de C. Sow.*
631, [629—640]	Protocardia purbeckensis (*de Lor.*)
[629—640]	„ sp. nov.
631	Unio *cf.* mantelli *J. de C. Sow.*
[641—651], 650	„ sp. (A)
631, [641—651]	*Cf.* Hydrobia chopardiana (*de Lor.*)
631	Valvata sp.
„	Viviparus sp.
[641—651]	Cypridea sp.
631, [641—651] 674, 679	Ostracoda, indet.
665	Elytra of beetle
628, 631 [629—640], 679	Fish remains [fragmentary]

The difficulty of identifying and utilising these few imperfect remains is increased by the fact that the invertebrate fauna of the Purbeck rocks of this country is scantily known, and has not been made the subject of any comprehensive and exhaustive study. Well preserved specimens are difficult to obtain, and the bivalves are frequently massed together and crushed. The Ostracoda are well known, but they seem to have a wide vertical distribution, and their value for purposes of detailed correlation is probably very slight.

The specimens of *Protocardia purbeckensis* from Brabourne show some variability, but they agree well with the figures of typical specimens from Villers in the Swiss Jura[1]. Sandberger states that this species occurs abundantly in the Middle Purbeck strata of England. Two specimens referred to *Protocardia* in the above list differ from *P. purbeckensis* by having more inflated

[1] P. de Loriol and A. Jaccard. 'Étude géol. et paléont. de la Formation d'Eau Douce Infracrétacée du Jura . . . de Villers-le-Lac,' *Soc. Phys. et d'Hist. Nat. de Genève*, vol. xviii., 1865, p. 43, pl. iii., figs. 12–16. C. L. F. Sandberger. 'Die Land- und Süsswasser- Conchylien der Vorwelt,' p. 37, pl. i., figs. 22, 22*a*, 1870. G. Maillard, 'Invertébrés du Purbeckien du Jura,' *Mém. Soc. Pal. Suisse*, vol. xi., 1884, p. 99, pl. iii., fig. 15.

and more nearly equilateral form. The general shape is suggestive of *Corbula*, narrow and produced posteriorly, and with high and rounded anterior profile. Fine concentric ribs and grooves ornament the surface in the lower half of the valve in an adult specimen, and the narrow posterior area has a sculpture of radial grooves exactly after the manner of *Protocardia*. The generic position is perhaps not determined beyond a doubt, but in the absence of material to show internal characters the specimens may be provisionally referred to *Protocardia*.

The little gasteropods brought into comparison with *Hydrobia chopardiana* in the above list may well be identical with that form; they are preserved for the most part as casts, and so far as their somewhat indefinite characters permit of comparison, they resemble figures of *Hydrobia chopardiana* given by de Loriol and Sandberger[1]. Sandberger states that this species is found abundantly, associated with *Protocardia purbeckensis*, in the Corbula Beds and Pecten Beds of the Middle Purbeck in Dorset.

The specimens of *Unio* mentioned in the above list as *Unio sp.* (A) do not exceed 15 mm. in length. The valves are elongated, narrowed anteriorly, and have greater height posteriorly. They are obliquely truncated at the posterior end. The greatest height occurs at about a quarter of the shell's total length from the posterior extremity; a valve 15 mm. in length has a maximum height of 9 mm. Perhaps the nearest described species is *U. subtruncatus* J. de C. Sow[2], but only an interior view of that form was figured by Sowerby, and it is difficult to make comparison. Our species (A) is certainly not identical with the shells from Villers-le-Lac, which Maillard considered to be *U. subtruncatus*[3]; it appears a little doubtful whether these were correctly identified, but they are distinguished from the Brabourne species by their less anteriorly situated umbones and by the greater height of the shell in front of the umbo and the much less marked slope of the antero-dorsal margin.

Portland Beds.

It has already been stated that the evidence obtained did not enable us to fix the upward limit of the Portland Beds with such precision here as at Penshurst. While there is definite palæontological proof that marine conditions did not persist in the strata above a depth of 680 feet, it was not possible to obtain fossils from the 10 feet or so of beds underlying this. At 688 feet *Trigonia* and other marine forms were found, and both here and below this depth some of the Mollusca were those which are very characteristic of the Portland Stone Series or Upper Portland Beds of Mr. H. B. Woodward's classification. The number of fossils yielded by this part of the core is so scanty that it is only possible to correlate the beds in bulk with the Portland Stone Series of Dorset, and no minor comparisons can be made; but it may be pointed out

[1] P. de Loriol and A. Jaccard, *op. cit.*, pl. ii., fig. 18. C. L. F. Sandberger, *op. cit.*, pl. i., fig. 25.

[2] In W. H. Fitton. 'Observations on some of the strata between the Chalk and the Oxford Oolite,' *Trans. Geol. Soc. Lond.*, ser. 2, vol. iv., 1836, p. 346, pl. xxi., fig. 15.

[3] G. Maillard, *op. cit.*, pl. iii., figs. 25–27.

that the strata at Brabourne which we class as Portlandian, just as in the two more westerly borings, comprise no equivalent of the Portland Sands. Correspondingly, the lower part of these Portland Beds in Kent, where complete as at Penshurst, may be correlated broadly with the "Upper Portlandian" division of Pellat's classification for the rocks in the neighbourhood of Boulogne, probably including also some of the uppermost beds (in O_2) of the "Middle Portlandian" which are above those yielding *Modiola autissiodorensis*.

It will be shown below that the upper part of the Upper Kimmeridge Clay is proved on palæontological grounds to be missing at this locality, thus supporting the suggestion given by the lithological change. Those beds which correspond with the Portland Sands, in the strict sense, are probably entirely absent here. There is no decisive evidence to show that the unconformity involves the absence also of any considerable part of the Portland Stone Series, but it may be noted that the lowest of these beds at Brabourne consists of calcareous conglomeratic rock, and there is nothing which agrees lithologically with the dark calcareous shale which formed the lowest few feet of the Portland Stone Beds at Penshurst. Since this dark shale at Penshurst occurred above the highest band of rock in which *Modiola autissiodorensis* was seen, it may be best correlated with the lowest part of the Portland Stone Series, to judge by analogy with the corresponding relations in Dorset. There the same *Modiola* is abundant in the top bed of the Portland Sands, but does not occur above it. Hence it is not unlikely that some lowest part of the Portland Beds as developed at Penshurst is unrepresented at Brabourne.

The reasons which lead us to confine the term Portland Beds to the Portland Stone Series or Upper Portland Beds of Mr. Woodward's classification, when dealing with these Kentish rocks, will be explained below in the discussion on the palæontology of the Upper Kimmeridge Clay, and again in the notes on the same part of the series at Penshurst where the Kimmeridge Clay is completely present.

Fossils from the Portland Beds; depth, 688 *feet to* 711 *feet.*

Depth in feet.	
688—709	Serpula sp.
688	Diastopora sp.
[689—710]	Astarte sp.
,,	Cardium sp.
,,	Exogyra sp.
,,	Lima *cf.* boloniensis *de Lor.*
,,	Modiola *cf.* boloniensis *de Lor.*
[689—710], 706, 710	Ostrea sp.
688	Pecten (Camptonectes) lamellosus *J. Sow.*
688, [689—710]	,, sp.
688	Pleuromya tellina *Ag.*
[689—710]	,, sp.
688	Trigonia *cf.* carrei *Mun.-Chalm.*
,,	,, gibbosa *J. Sow.*
[689—710]	,, sp. [clavellate]
710	"Holcostephanus" *cf.* bononiensis (*de Lor.*) [Blake's interpretation]
,,	"Holcostephanus" *cf.* giganteus (*d'Orb.*) [non *Sow.*]
689, [689—710]	Crustacean [fragment of claw]
[689—710]	Fish scale

This list calls for little remark. The abundance of *Serpula* throughout the series is a notable feature. Specimens of the two named *Trigoniae* were seen only from near the top of the series, and the same must be said of *Pecten lamellosus*, which is represented by numerous large valves at a depth of 688 feet; but these isolated occurrences in the core can be considered to give no idea of the true vertical distribution. The two ammonites were found just at the base, which may perhaps not be quite the true base of the series. The absence of *Modiola autissiodorensis* and of other forms which occurred in the top part of the Upper Kimmeridge Clay at Penshurst—the equivalent of the Portland Sands—is most noteworthy.

Kimmeridge Clay.

In contrast to the record yielded by the Dover section, the Kimmeridge Clay Series at Brabourne is much more nearly complete. We find here the whole of the beds containing *Exogyra virgula*, and these are overlain by about 65 feet of Upper Clays of more purely argillaceous character which have not yielded that species. We have seen that the palæontological evidence shows that at Dover not only are the Virgula Beds incompletely present in their upper part, but the Upper Clays are entirely unrepresented.

The distinction made on palæontological grounds between the Upper Clays and the underlying Virgula Beds at Brabourne is a well marked one, and the evidence upon which it is founded can be easily recognised. It is only in the upper division that we meet with "*Holcostephani*" resembling *H. pallasianus*, and there also we see that species of *Perisphinctes* are much more numerous than in the Virgula Beds. They include some forms which show "polyplocoid" degeneration. The commonest fossil in the Upper Clays is *Modiola autissiodorensis*, which is abundantly distributed; its downward range extends to within a few feet of the level at which *Exogyra virgula* became a dominant fossil. It was only at one horizon where these two species were found in association, and that was at a depth of 770 feet, the highest point at which any specimen of *Exogyra virgula* was seen. Amongst other characteristic species found only in the Upper Clays are those we have named *Astarte* cf. *mysis* and *Aporrhais* cf. *piettei*. It may be added that *Orbiculoidea* is of frequent occurrence in these upper beds, but was not found in the Virgula Beds at Brabourne, and is represented by only a single specimen in our more plentiful material from those beds at Dover[1]. *Protocardia morinica*, which occurs abundantly in the Upper Clays, does not, according to our evidence, extend far downwards in the beds with *Exogyra virgula*. It is only at Brabourne that its downward distribution can be tested, and allowance must be made for the comparatively scanty nature of the material, but this fossil was only found in the uppermost 60 feet of the beds containing *Exogyra virgula*. At

[1] The frequency of *O. latissima* in the clays overlying the Virgula Beds has been noted in other parts of the country. The few feet of papery shale at the top of the well-known section at Ely no doubt correspond to the lower part of our Upper Clays in Kent. *See* T. Roberts, 'The Jurassic Rocks of the Neighbourhood of Cambridge,' 1892, pp. 66, 67.

Dover, where the Virgula Beds had been partly denuded away, it was not seen to occur[1].

We have drawn the base-line of the Upper Clays at a depth of 775 feet, for this is the point below which no specimen of *Modiola autissiodorensis* was found, and it also marks the upward limit of the beds in which *Exogyra virgula* is abundant. While the fauna of the Upper Clays stands in strong contrast to that of the Virgula Beds when generally considered, the distribution of these two species gives the chief evidence which we are able to utilise in fixing upon an actual division line; but the coincidence between the downward limit of range of one of these lamellibranchs and the upward limit of the other appears to furnish a most appropriate guide. We may use it with the greater confidence because even the cores of these borings suffice to show that these two species, the one above the dividing-line and the other below it, were both frequent in their occurrence.

As regards a correlation, we have observed in connection with the Dover section that the Virgula Beds there may perhaps correspond with the sub-zone of *Ostrea deltoidea* and a part of the overlying sub-zone of *Exogyra virgula* of Mr. H. B. Woodward's classification—that is, broadly speaking, with the Pterocerian of Continental authors. At Brabourne, where the Virgula Beds are complete in their upward extent, we must also have the equivalent of the Caletanus Beds of French localities; and judging by the distribution of *Exogyra virgula* in the neighbourhood of Boulogne, it is highly probable that the overlying Erinus Beds and even part of the Gigas Beds are represented in the top part of our Virgula Beds. In the Boulogne district the downward distribution of *Modiola autissiodorensis*, according to de Loriol and Pellat, extends to the upper Erinus Beds (M_1 of Pellat's scheme), while the upward limit for *Exogyra virgula* is said to be in the overlying Gigas Zone. Looking at the matter from the broad standpoint which alone is possible with the limited evidence at our command, we consider that our division line between Virgula Beds and Upper Clays may correspond with some position above the Erinus Beds within the overlying Gigas Zone.

Our Upper Clays, therefore, remain to be correlated broadly with the upper part of the "Lower" and with the "Middle Portlandian" of Pellat's classification (perhaps excluding Pellat's O_2 or part of it), thus with most of that part of the sequence which the late Prof. J. F. Blake regarded first as the upper division of the Kimmeridge Clay of this country, afterwards as a series separable from the Virgulian below and the true Portland Beds above, to which he applied the name "Bolonian." He included the Portland Sand in this division, and his proposed nomenclature has not met with general acceptance. In Dorset, the type-area for the classification of the Upper Kimmeridge Beds, the lower limit of the Bolonian would fall in the middle of a clayey series, indicated by a purely palæontological boundary which has perhaps not yet been even so

[1] The meaning with which we have employed the term "Virgula Beds" in these Kentish sections has already been explained in the remarks which precede the lists of fossils from the Kimmeridge Beds at Dover. *See* p. 115.

well defined as in the present case at Brabourne. Moreover, in the Kimmeridge district the clays above the Virgula Beds, not characterised by *Exogyra virgula* but by "*Holcostephani*" of the *H. pallasianus* type, *Orbiculoidea latissima* and *Lucina minuscula*, amongst other forms, must reasonably be considered to form the upper part of the Kimmeridge Clay. We have, therefore, spoken of these corresponding beds revealed in the Kentish borings as the Upper Clays of the Kimmeridge Series, and although the top part of our Upper Clays doubtless comprises beds equivalent to the Portland Sands, even with the restricted meaning with which that term has been employed by the Geological Survey, yet in Kent we can make no division between Upper Kimmeridge Clays and Portland Sands either on lithological or palæontological grounds, but must regard the whole as forming here the upper portion of a stratigraphical unit. Hence we are led to use the term Upper Kimmeridge Clays in a rather more comprehensive sense than we should find it necessary to do in Dorset, and we should be tempted to adopt Blake's term Bolonian, which he applied to approximately the same strata, were it not obvious that the lower beds must correspond with a substantial part of the true Kimmeridge Clay of the type-locality.

Having broadly defined the limits of our Upper Clays, we may now consider in greater detail the question of their upper boundary. It has been mentioned in a previous chapter that there is some sign of a break at the top at Brabourne, and the question arises whether these beds are completely represented at this locality or whether there is any marked unconformity by which they are separated from the overlying Portland Beds. The best answer to this may be obtained by a palæontological comparison with the upper part of the Upper Clays at Penshurst, where, as we have seen, the Portland Beds make a conformable series with the Kimmeridge Clay below. Taking the list of fossils from the Upper Clays at Brabourne, we find that it does not agree well with that from the uppermost 250 feet of Upper Clays at Penshurst, but most closely resembles the assemblage found there below a depth of 1,500 feet, where the fauna is well characterised by the presence of *Orbiculoidea latissima*, *Astarte* cf. *mysis*, *Cyprina sp.* (A), *Protocardia morinica*, and *Aporrhais* cf. *piettei*, all of which must have occurred in abundance. There are also a few traces of fragmentary fish-remains at both localities. We see that in the highest 250 feet of strata at Penshurst there was a much greater prevalence of species of "*Holcostephanus*" than in the highest beds at Brabourne, and that no traces of the above forms were revealed by the boring-cores. Moreover, between the depths of 1,360 feet and 1,460 feet there occurred at Penshurst a species of *Grammatodon*, entered as *Grammatodon* cf. *rhomboidalis* in our list, which was of such abundant occurrence that we should certainly expect to find some traces of it at Brabourne had beds of corresponding position in the series been penetrated; but no specimen of this characteristic shell was observed to occur there. Further, no specimen of *Cyprina implicata* was found at Brabourne, while this was commonly represented in the Penshurst core at depths between 1,320 feet and 1,388 feet. *Modiola autissiodorensis*, which was of help in setting

a lower limit to our Upper Clays, cannot be utilised in the same manner in this comparison, because its upward range extends throughout the highest 200 feet at Penshurst, up to the line which we have taken as the top of the Kimmeridge Clay. But it may be noted that the specimens from the highest beds at Brabourne are the large, posteriorly expanded valves such as are found at Penshurst below a depth of 1,500 feet, and not the smaller and relatively shorter individuals which occur in the top beds at Penshurst and also in the top part of the Portland Sands of Dorset.

In reading this evidence two possible sources of error must be borne in mind, the influence of a change of facies and the element of chance. It has been remarked that the Kimmeridge Clay at Penshurst is generally speaking of a more purely argillaceous character than at Brabourne, and it is conceivable that this might influence the distribution of any single species. Yet we cannot think it probable that lithological differences which did not affect the distribution of the above-mentioned forms which occur below 1,500 feet at Penshurst could have played any part in determining the absence of the *Grammatodon* and *Cyprina* at Brabourne; and in regard to the "*Holcostephani*" the question of lithology is with still less probability to be taken into account in explaining their relative rarity at Brabourne and abundance in the highest beds at Penshurst. We may note that some of the species of the Upper Clays of Penshurst occur in the Upper Kimmeridge Clay in Lincolnshire, in a matrix which offers as strong a contrast to that at Penshurst as is shown by the Brabourne material. Furthermore, the type of rock in the Upper Clays at Brabourne is much less strongly contrasted in character with the uppermost 250 feet or so of beds at Penshurst than with the strata below a depth of 1,500 feet which we find to contain the more closely comparable fauna. We conclude that the difference of facies is practically a negligible factor. As regards the other cause of error, the presence of the highest Brabourne fossils in the strata below 1,500 feet and their absence above that depth at Penshurst, coupled with the abundance of the *Grammatodon* and *Cyprina* and of certain forms of "*Holcostephanus*" in these uppermost beds and their absence at Brabourne, may, we think, be considered to form a sufficiently strong array of facts to outweigh the risk of a misreading owing to the chances of collection. The reasons for believing the depth of about 1,500 feet at Penshurst to correspond with the top of the Upper Clays at Brabourne are further discussed in the account of the palæontology of the Penshurst boring.

We conclude that in high probability the unconformity at the top of the Upper Clays at Brabourne is a not inconsiderable one; yet it must be allowed that it is not so great as might appear from the actual thickness of the strata at Penshurst which are unrepresented at Brabourne. The rapid thickening of the sediments in a westerly direction must be borne in mind. If our reading be a correct one, the disparity in the thickness of the Upper Clays at these two localities will not be so great as if no measurable unconformity had been recognised at Brabourne; yet, even though

we deduct the uppermost 250 feet at Penshurst, we must believe that about 65 feet of beds at Brabourne are represented by at least 370 feet at Penshurst. We shall later on have occasion to examine the palæontological evidence which shows that only the Upper Clays were represented in the Penshurst boring, and we shall find that not only did the boring not pass into the Virgula Beds, but that possibly the base of the Upper Clays was not reached. The westerly expansion may therefore be really even greater than from 65 feet at Brabourne to 370 feet at Penshurst; but even so, if the same ratio of accumulation were maintained to the top of the Upper Clays in these two localities, it is clear that only a little more than 40 feet of beds are missing at Brabourne.

To revert to the question of correlation, we may take the Upper Clays at Penshurst to represent the Portland Sand in the broader sense in which the term was employed by Blake, as well as a great part of the Upper Kimmeridge Clay. As shown by the fossils, the Portland Sands as defined by the Geological Survey will be included, for at St. Alban's Head they contain "*Ammonites biplex*" (probably a "*Holcostephanus*" resembling *H. pallasianus*) and *Modiola autissiodorensis*. Our Upper Clays will thus correspond in their top part with some of Pellat's "Middle Portlandian" in the Boulogne district, certainly the division O_1 and possibly some lower part of O_2. At Brabourne the top of the Upper Clays may perhaps fall below the base of the Portland Beds of Dorset as defined by the Geological Survey, but will probably embrace some lower part at least of the Portland Sand as understood by Blake. Our evidence does not permit us to say how much of Pellat's "Middle Portlandian" is included, but we think it probable that the lower beds of that division, in which *Protocardia morinica* is abundant, may be wholly or in part represented.

The Virgula Beds at Brabourne are characterised throughout by the presence of the name-fossil, but it was evidently most plentiful in their upper part, and towards the base not only was the species more rarely met with, but the individuals were seen to be of smaller size than those above, a point which was also noted at Dover in the correspondingly low beds[1]. Comparatively few species were yielded by the cores from the uppermost 60 feet of the Virgula Beds at Brabourne, although individuals were numerous. It is just below a depth of 835 feet where the highest occurrence of *Gervillia kimmeridgensis* was noted. This was found right down to the topmost beds of the Upper Corallian. It was below a depth of 835 feet also that the small, finely-ribbed *Astarte ingenua* was obtained in abundance. This species, however, was not seen in the lowest 50 feet of the Virgula Beds. Below a depth of 850 feet the shells of *Nucula* commonly ascribed to *N. menkei* were found, and these were met with down to the base of the formation, as at Dover. *Ostrea deltoidea* was only seen as the base is approached, and it will be recalled that at

[1] Compare also H. Douvillé. 'Note sur la partie moyenne du terrain jurassique dans le bassin de Paris,' *Bull. Soc. Géol. France*, ser. 3, vol. ix., 1881, p. 450, footnote.

Dover this fossil was found only in a corresponding position. An ammonite referred by Mr. Buckman to *Physodoceras orthocera* occurred at 10 feet above the base, and this is of interest as a guide-fossil which is found in the Lower Kimmeridge Clay or Pterocerian of French localities. There is difficulty in deciding upon a base-line for the Virgula Beds here, just as at Dover, because there is neither a lithological nor a palæontological break between the Upper Corallian and Lower Kimmeridge strata. This matter has already been briefly discussed in the remarks which precede the lists of fossils from the Corallian Series at Dover.

When discussing the fauna of the Virgula Beds at Dover we have had occasion to set forth the evidence which shows that these beds are there incomplete in their upward extent. From a comparison of the fossils we have concluded that in all probability the uppermost 60 feet of the Virgula Beds at Brabourne are unrepresented at Dover, and it therefore becomes evident that the westerly expansion of this part of the series is not really so great as appears from a comparison of the actual thickness of Virgula Beds in the two localities. Still, assuming that we have succeeded in giving an equivalent base-line in the two sections, the difference in thickness is sufficiently striking, for we find that 45 feet of strata at Dover expand to 138 feet at Brabourne. If we suppose that the same ratio of accumulation was continued to the top of the Virgula Beds in the two localities, it is evident that only about 20 feet of these beds are missing at Dover.

(1.) *Fossils from the Upper Kimmeridge Clays; depth,* 711 *feet to* 775 *feet.*

(a). Depth, 711 feet to 738 feet.

Depth in feet.	
[725—737]	Lingula ovalis *J. Sow.*
712, [725—737]	Orbiculoidea latissima (*J. Sow.*)
[725—737]	Astarte *cf.* mysis *d'Orb.*
,,	Corbula deshayesea *Buvign.*
712	Cyprina sp. (A)
,,	Exogyra sp.
,,	Isodonta kimmeridiensis *Dollf.*
712, [725—737]	Lucina *cf.* lirata *Phill.*
735, ,,	Modiola autissiodorensis (*Cott.*)
711, ,,	Ostrea sp.
712	Pecten (Syncyclonema) demissus *Phill.*
712, 718, [725—737]	,, (Camptonestes) morini *de Lor.*
[719—724]	Pleuromya recurva (*Phill.*)
712, 720	Protocardia morinica (*de Lor.*)
712	Pteria (Oxytoma) inequivalvis ? *J. Sow.*
,,	Trigonia voltzi ? *Ag.*
712, [725—737]	,, sp.
[725—737]	Unicardium ?
,,	Aporrhais *cf.* piettei (*Buvign.*)
,,	Harpagodes sp.
,,	Patelliform gasteropod
711	"Holcostephanus" pallasianus ? (*d'Orb.*)
[725—737]	*Cf.* Perisphinctes eudichotomus (*Zitt.*)
,,	Perisphinctes *cf.* lictor (*Fontannes*)
712	? Perisphinctes rotundus (*J. Sow.*)
[725—737]	Perisphinctes sp.
,,	Fish fragments

(h). Depth, 738 feet to 775 feet.

Depth in feet.	
740, [738—755]	Lingula ovalis *J. Sow.*
[738—755]	Astarte *cf.* mysis *d'Orb.*
770	Exogyra virgula (*Defr.*) [only seen near base]
[738—755]	Lucina *cf.* lirata *Phill.*
[738—755], 770	Modiola autissiodorensis (*Cott.*)
775	Ostrea sp.
765	Pleuromya sp.
[738—755], [756—783]	Protocardia morinica (*de Lor.*)
[738—755]	Aporrhais *cf.* piettei (*Buvign.*)
,,	"Holcostephanus" sp.
,,	Perisphinctes discobolus (*Fontannes*)
765	,, geron *Zitt.* [Quenstedt's reading]
[738—755]	,, *cf.* lusitanicus *Siem.*

Of the fossils found throughout the Upper Clays, *Modiola autissiodorensis* is the commonest. Except for their rather larger size, the specimens from Brabourne which we have attributed to this species agree very closely in shape with the original figure given by de Loriol and Cotteau of an example from the Zone of *Pinna suprajurensis* in the Yonne[1]. The species also occurs in the Boulogne district throughout Pellat's "Lower" and "Middle Portlandian," and it has been recorded by Mr. H. B. Woodward from the upper beds of the Kimmeridge Clay and from the Portland Sands of this country, and also by the late Professor J. F. Blake from the strata classed by him as Bolonian. It can be readily recognised by its well-marked type of ornamentation, which consists of two separate groups of delicate and crowded radiating linear ribs. One group of these passes from the umbo over the anterior region of the valve, while the larger group radiates obliquely backwards over the dorsal part of the valve and spreads out to terminate at the posterior and postero-ventral border. A smooth space devoid of ornaments, narrow near the umbo and very rapidly broadening below, is left between the two bundles of fine ribs. Further remarks on this important species will be found to follow the list of fossils from the uppermost Kimmeridge Beds of Penshurst.

The remains of ammonites recovered from these beds by the boring are very unsatisfactorily preserved and are so fragmentary that their identification is a matter of great difficulty. Some of the forms of *Perisphinctes* show marked "polyplocoid" degeneration. Thus, a specimen from between 738 feet and 755 feet in depth, referred by Mr. Buckman provisionally to *P. discobolus*, possesses a distinctive ornamentation of unevenly spaced primary ribs, some of which are stronger than others, dividing at about the middle of the flank, or a little externally to this, into groups of from two to four secondary ribs. Intercalary secondary ribs also occur. The specimen has suffered from crushing, so that the flatness of the relatively extensive flank may have become somewhat emphasised. Yet the original whorl-section would be likely to show little more rotundity since the umbilical marginal slope has suffered in no marked degree but is still well indicated.

[1] P. de Loriol and G. Cotteau. 'Monographie paléont. et géol. de l'étage Portlandien du départ. de l'Yonne,' *Bull. Soc. Sci. Hist. et Nat. de l'Yonne*, ser. 2, tome i, 1868, p. 189, pl. xii., fig. 8.

Although the figure of *P. discobolus*[1] shows a slightly greater crowding of the peripheral ribs, the features shown by the Brabourne specimen must certainly suggest intimate relationship with this species and allied forms, such as *P. lictor*, which are characterised by this irregular type of ribbing and by high whorl-section and flattened flanks. The reference to these forms, which were first described from the so-called Zone of *Ammonites tenuilobatus* of Crussol (Ardèche), might seem to point to a "zonal impossibility." This could be explained either by assuming that there has occurred a repetition of the polyplocoid developmental phase among species of *Perisphinctes*, and this appears quite probable; or that there has been a misleading and too comprehensive application of the zonal name to a series in Ardèche comprising beds of possibly Upper Kimmeridge as well as Lower Kimmeridge and Upper Corallian age. Yet it should be remembered that the ammonite-fauna of our Kimmeridge Series in England is imperfectly known and calls for much further study, and is, moreover, inadequately represented in the various collections. The names of some of the species in these lists, as pointed out by Mr. Buckman, should therefore be regarded as provisional and should be accepted with due reserve.

Small specimens of *Astarte* with prominent and relatively coarse concentric costate ornamentation were met with in considerable numbers in the Upper Clays, but were not seen in the *Exogyra virgula* Beds below. These are usually preserved as casts with remnants of the shell adhering, and the original outer surface in most cases is not to be seen. These shells show considerable variation both in their shape and in the coarseness of their ribbing, but the true limits of variation in these particulars are somewhat obscured by the accidents of preservation. It is probable that amongst the specimens which we have brought into comparison with *Astarte mysis* d'Orb., more than a single species is represented, but the available material has not sufficed to establish this beyond doubt. Some examples, though agreeing well in shape with *A. mysis* as figured by Dollfus[2], differ in being more coarsely ribbed, and in this feature they more closely resemble a shell from a higher horizon ascribed by de Loriol to *A. scalaria* Roem[3].

The specimens ascribed in these lists to *Protocardia morinica* doubtless represent a species which has been repeatedly recorded from Upper Kimmeridge beds in this country under the name *Cardium striatulum* J. de C. Sow. Sowerby's type-specimen came from the argillaceous limestone above the coal at Brora which yielded also *Kepplerites gowerianus*, and is of Kellaways age. It is extremely doubtful whether any close relationship exists between these Kellaways and Upper Kimmeridge forms of

[1] E. Dumortier and F. Fontannes. 'Descript. des Ammonites de la Zone à Ammonites tenuilobatus de Crussol (Ardèche),' *Mém. de l'Acad. de Lyon, Classe des Sci.*, tome xxi., 1876, pl. xiii.

[2] A. Dollfus. 'La Faune Kimméridienne du Cap de la Hève,' 1863, pl. xi., figs. 1–4.

[3] P. de Loriol and E. Pellat. 'Monographie paléont. et géol. des étages supérieurs de la Formation Jurassique des Environs de Boulogne-sur Mer,' *Mém. Soc. Phys. et d'Hist. Nat. de Genève*, tome xxiv., part i., 1875 pl. xv., fig. 6.

Protocardia, which differ slightly in shape and ornamentation, and we therefore adopt de Loriol's name[1]. In the neighbourhood of Boulogne the species occurs most numerously in the "Middle Portlandian" of Pellat, but is also found below in the upper part of Pellat's "Virgulien"; that is, at a horizon some way down in the upper part of our Virgula Beds in Kent, though possibly not quite so low as the downward limit for the species which we have observed at Brabourne.

A *Cyprina* occurring here in the top bed is of interest because the same form is found at Penshurst below a depth of 1,600 feet. This is *Cyprina sp.* (A) of our lists. It is much more elongated and posteriorly produced than *C. implicata,* which occurs higher up at Penshurst, and it bears a much closer resemblance to Blake's *C. elongata* of the Portland Beds.

Specimens of *Aporrhais* which appear to be most closely comparable with *A. piettei* (Buv.) of the French Kimmeridge beds occur both at Penshurst and Brabourne in these Upper Clays. They are not sufficiently well-preserved for an exhaustive comparison, but so far as can be seen they show considerable agreement with some of the specimens included by Piette in that broadly comprehended species[2]. One feature which perhaps indicates a separate position is the smaller number of secondary spiral ribs between the major ribs on the body-whorl and alar expansion shown by the Kentish specimens. Examples ascribed to *Aporrhais intermedius* Piette [= *Chenopus piettei* Buv.] are described and figured by de Loriol from the Caletanus Zone of the Haute-Marne[3]; thus from a lower horizon than that at which this allied gasteropod was found at Brabourne and Penshurst.

The determination of a specimen from the upper part of the Upper Clays as *Isodonta kimmeridiensis* in the above list must be accepted with some reserve. Our specimen at least very closely resembles Dollfus's figure, but he recorded the species from the Calcaires à Trigonies of Cap de la Hève, where it was stated to be very rare; therefore from a considerably lower horizon than the occurrence at Brabourne.

Shells which may be ascribed provisionally to *Lucina* are so well represented in the cores above the *Exogyra virgula* Beds, occurring in association with *Aporrhais* cf. *piettei,* as to indicate that they were there in considerable profusion, and they therefore deserve special mention. Examples from the more finely laminated beds are much flattened and crushed, but a specimen which is perhaps identical, occurring in the top part of the underlying impure sandy limestone with *Exogyra virgula,* retains its convex form and shows a somewhat different aspect, which may perhaps be entirely ascribed to the mode of preservation. It is impossible, in view of this difference of preservation and the fact that we have only a single specimen from the top of the *Exogyra virgula* Beds,

[1] P. de Loriol, E. Royer and H. Tombeck. 'Descript. géol. et paléont. des Étages Jurass. Supér. de la Haute-Marne,' *Mém. Soc. Linn. Norm.*, vol. xvi., 1872, p. 241, pl. xiv., figs. 9, 10.

[2] E Piette. 'Paléont. Française. Terr. Jurass.,' vol. iii., Gastéropodes, p. 306, 1876; pl. xliv., figs. 9–13; pl. lii., figs. 2–5, 15, 16; pl. lvii., figs. 1–15.

[3] P. de Loriol, E. Royer, and H. Tombeck. 'Descript. géol. et paléont. des Étages Jurass. Supér. de la Haute-Marne,' *Mém. Soc. Linn. Norm.*, vol. xvi., 1872, p. 140, pl. ix., figs. 15–17.

to assert the identity of the two forms, but for the present they may be regarded as the same. Even if existing at the top of the lower division, according to our evidence this species became much more abundant in the overlying beds with *Astarte* cf. *mysis* and *Aporrhais* cf. *piettei*. Here, the largest individual found measures about 45 mm. in length and 37 mm. in height. The umbo is subcentral, and the outline in front of it is slightly excavated. The hinge-line anteriorly to the umbo is almost straight and extends far forward, but on the posterior side it slopes away. The frontal border forms a sweeping curve which passes imperceptibly into the regularly curved lower margin. There is a slight truncation at the posterior border. The surface is ornamented by well-spaced concentric lamellar ridges sometimes as much as 3 mm. apart, and numerous fine intermediate concentric striæ.

This form is closely comparable with *Lucina lirata* Phill., of the Kellaways Rock, which, however, is perhaps a little more inequilateral in shape. But it is certainly with *L. lirata* that an apt comparison can be made. Shells of very similar general type are known to occur at still lower horizons—as exemplified by *L. bellona* d'Orb. (= *L. lirata*, var. *transversa* d'Arch.)[1] from the Great Oolite Series in France—and also in the Corallian rocks of this country; but the question of their precise relationships could only be elucidated by detailed study. Specimens closely resembling these from Brabourne are known to occur in the Kimmeridge Clay of Dorset, but they are usually imperfectly preserved and have hitherto not been thoroughly studied. Some of them may be specifically identical with the examples from Brabourne. A species described by G. Krause as "? *Lucina scaphoidea* sp. nov." from the Kimmeridge Beds with *Exogyra virgula* in the deep-boring at Heilsberg may also possibly be related[2].

The appearance of such a name as *Pleuromya recurva* in the above list must invite a question as to the accuracy of the determination. Much work remains to be done in the classification of the species of *Pleuromya* and allied genera in our Jurassic strata, and in the meantime the above reference to a species which was first described from a very much lower horizon must be regarded as quite tentative.

(2.) *Fossils from the Virgula Beds; depth, 775 feet to 973 feet.*

(a). Depth, 775 feet to 835 feet.

Depth in feet.	
[793—812]	Corbula ?
[784—792]	Exogyra virgula (*Defr.*)
„	Lucina *cf.* lirata *Phill.*
„	„ sp. (A)
775, 785, [784—792]	Ostrea sp.
[784—792]	Pleuromya recurva (*Phill.*)
[784—792], [813—834]	Protocardia morinica (*de Lor.*)
785	Trigonia *cf.* pellati *Mun.-Chalm.*
[784—792]	„ sp. [clavellate]
785	Unicardium sp.
[784—792]	Perisphinctes ?

[1] A. d'Archiac. 'Descript. géol. du départ. de l'Aisne,' *Mém. Soc. Géol. France*, tome v., part 2, 1843, p. 372, pl. xxvi., fig. 3.

[2] G. Krause. 'Ueber Diluvium, Tertiär, Kreide und Jura in der Heilsberger Tiefbohrung,' *Jahrb. d. k. preuss. geol. Landesanst.* für 1908, Band xxix., Heft. 2, 1908, p. 269, pl. v., fig. 6; pl. vi., figs. 5, 6.

(b). Depth, 835 feet to 900 feet.

Depth in feet.	
[878—890]	Wood [traces]
[878—890], [890—899]	Serpula sp.
[878—890]	Anatina (Cercomya) *cf.* striata (*Ag.*)
[836—853], [878—890]	Anomia sp.
[836—853], 850, [854—878]	Astarte ingenua *de Lor.* [not seen in the lowest 25 feet]
[854—878]	Corbula sp.
[878—890]	Cucullaea?
[836—853], 850, [854—878] / [878—890], [890—899]	Exogyra virgula (*Defr.*)
[836—853]	Gervillia kimmeridgensis *d'Orb.*
[878—890]	Lucina sp. (A)
855, [890—899]	Nucula menkei *F. A. Roem.* [not seen above 850 feet]
855	Ostrea sp.
[878—890]	Pecten (Syncyclonema) demissus? *Phill.*
,,	Pleuromya recurva? (*Phill.*)
,,	Trigonia monilifera? *Ag.*
871, [878—890] / [890—899]	,, sp. [clavellate]
[890—899]	"Holcostephanus" *cf.* stephanoides (*Oppel*)
855	Perisphinctes laufenensis? *Siem.*

(c). Depth, 900 feet to 973 feet.

[900—921]	Lingula ovalis *J. Sow.*
928	Anomia?
[900—921]	Astarte ingenua *de Lor.* [not seen below 920 feet]
[930—960]	Exogyra nana? (*J. Sow.*)
[923—927], [930—960]	,, virgula (*Defr.*)
973	Gervillia kimmeridgensis *d'Orb.*
928	Lucina sp.
970, [963—972]	Nucula menkei *F. A. Roem.*
[900—921]	,, *cf.* ,, ,,
928	Ostrea deltoidea *J. Sow.*
[900—921]	Pecten *cf.* billoti *Cont.*
,,	,, (Syncyclonema) demissus *Phill.*
,,	Pholadomya sp.
[900—921], 928	Pleuromya sp.
[900—921]	Thracia depressa? (*J. de C. Sow.*)
[930—960]	Cerithium sp.
961, [963—972]	"Holcostephanus" *cf.* desmonotus (*Oppel*)
963	Physodoceras orthocera (*d'Orb.*)

The occurrence of *Exogyra virgula* in these beds has already been discussed in the remarks which precede the lists of fossils from the Virgula Beds of Dover, and also in the general observations relating to the Kimmeridge fossils of the Brabourne boring. *Protocardia morinica,* which we have seen to be common in the Upper Clays, occurs also in the Virgula Beds here down to some depth below 813 feet, but not below 835 feet. At a depth of 785 feet the abundance of the shells of large clavellate *Trigoniæ,* including some which are very closely comparable with *T. pellati,* forms a noticeable feature. Even in the restricted area of the boring-core the valves are seen to be crowded together, and they must have occurred in this bed very numerously. It is possible that these shells belong to two species.

Lucina cf. *lirata,* which has been discussed above, is, we think, represented here in the upper beds, from a depth just above 792 feet, by a specimen which bears close resemblance to those of the Upper Clays, but is somewhat differently preserved. In addition to this there is another form which may be referred to

Lucina. It is scantily represented in the core from a depth between 784 feet and 792 feet, and is distinguished from the above by having a more nearly circular outline and by the closer spacing of the concentric lamellar ornaments. One example obtained measures 28 mm. in length and in height, while the ornamenting ridges are situated about 1 mm. apart from one another. This is *Lucina sp.* (A) of the list. It may be closely compared with a shell which was described from a corresponding horizon in the Haute Marne by de Loriol under Roemer's name *L. substriata*[1]. This name, even if correctly used in that instance, which appears doubtful, has, we believe, been too freely applied on the Continent, and it seems highly probable that shells from about the same horizon near Boulogne, which have been described under the same appellation by de Loriol[2], represent in reality another species. They are distinguished by much finer and more crowded ornamentation and cannot be brought into close comparison with the specimens from Brabourne, which show better agreement, again, with shells from the Upper Corallian rocks near Boulogne, which have been referred by de Loriol to *L. imbricata* Contejean[3]. Our imperfect materials do not, however, permit of a definite determination.

No species of *Astarte* closely comparable with that which was found to be so characteristic in the Upper Clays was seen in the Virgula Beds; but at depths between 835 feet and 921 feet there were numerous specimens of a small form characterised by fine and crowded concentric linear ribs. These may be referred to *Astarte ingenua* de Loriol, which occurs in the Virgulien of the Boulogne district. The discrimination of specific differences in these small finely-ribbed forms of *Astarte* is always a matter of difficulty, but in the present case the agreement with the figure given by de Loriol[4] appears to be so close as to justify this definite determination. This little shell must have occurred very numerously at one level passed through at a depth between 854 feet and 878 feet, for it is found in great numbers in a single hand-specimen.

Specimens of *Nucula* which may be taken to represent the Lower Kimmeridge form commonly referred to F. A. Roemer's *N. menkei*, were first seen below a depth of 850 feet, and were found to occur down to the base of the formation. It may be remembered that at Dover these were met with at the very top of the remnant of Virgula Beds preserved there. Few of our specimens from these two localities are well preserved, and some are crushed or fragmentary. Some variation in the outline suggests that we may possibly be including examples of more than one species under this name; but all agree in the narrowed and

[1] P. de Loriol, E. Royer and H. Tombeck. 'Descript. géol. et paléont. des Étages Jurass. Supér. de la Haute-Marne,' *Mém. Soc. Linn. Norm.*, vol. xvi., 1872, pl. xvi., fig. 2.

[2] P. de Loriol and E. Pellat. 'Mon. paléont. et géol. de l'étage Portl. des environs de Boulogne-sur-Mer,' *Mém. Soc. Phys. et d'Hist. Nat. de Genève*, vol. xix., part 1, 1866, pl. vi., fig. 11.

[3] P. de Loriol and E. Pellat. 'Monographie paléont. et géol. des étages supér. de la Formation Jurassique des Environs de Boulogne-sur-Mer,' *Mém. Soc. Phys. et d'Hist. Nat. de Genève*, vol. xxiv., part 1, 1875, pl. xiv., fig. 5.

[4] P. de Loriol and E. Pellat, *ibid.*, pl. xv., fig. 3.

pointed character of the posterior extremity, which in this genus is the end towards which the umbo is more nearly approximated. In the neighbourhood of Boulogne this species has been cited as occurring at horizons below and above that at which these shells were found at Dover and Brabourne; but at Cap de la Hève it has been found in association with a fauna, of uppermost Corallian age, which is strongly reminiscent of that found in the lower part of our Virgula Beds, the only part of the series where it has been seen in Kent.

A specimen of *Pecten* from between 900 feet and 921 feet, ascribed to *P. demissus* in the above list, has considerable height in relation to length, and is marked by a concentric banding of the surface (? right valve). It agrees very closely with a figure of the form called *P. vitreus* Roem. by de Loriol, from the Tenuilobatus Zone of Oberbuchsitten[1]. De Loriol was unable to decide whether *P. vitreus* Roem. and *P. demissus* Phill. should be separated as distinct species. We are in the same position of doubt, for this is one of the groups which have been insufficiently studied, and the present memoir does not give the opportunity for working out in detail the relations of these indefinitely characterised forms of *Syncyclonema*. The specimens at hand from various horizons in these borings are more or less imperfect, and in our lists the name *P. demissus* can in some instances only be employed provisionally; consequently a too precise meaning must not be attached to it.

We see that amongst the somewhat scanty remains of ammonites obtained below a depth of 835 feet there are specimens which are identical with some from the corresponding beds at Dover. Remarks on the ammonites which follow the list of fossils from the Virgula Beds at Dover may be read in connection with this corresponding fauna from Brabourne also. One specimen from near the base of the formation at this boring is of interest, for, although crushed and fragmentary, its characters relate it very closely to *Physodoceras orthocera*, with which Mr. Buckman has ventured to identify it. It shows a broad and smooth peripheral area and a series of spaced spinous marginal umbilical tubercles. This is the name-fossil of the Orthocera Zone of the Continent.

Corallian Series.

When dealing with the palæontological features of the Corallian Series as seen in the Dover section, we have already explained the difficulty of separating the Upper Corallian Beds from the overlying Virgula Beds of the Kimmeridge Clay. The same remarks apply to the Brabourne section, where the fauna of the lower formation is seen to merge without sudden change of type into that of the overlying series. The assemblage of fossils found here in the Upper Corallian beds is very closely comparable with that met with at Dover, and the most apparent differences are only such as could be accounted for by the chances of collection. Here, as at Dover, one might have little hesitation in classing

[1] P. de Loriol. 'Mon. paléont. des couches de la zone à *Ammonites tenuilobatus* d'Oberbuchsitten et de Wangen (Soleure),' part 2, p. 93, pl. xiii., fig. 3. *Mém. Soc. Pal. Suisse*, vol. viii., 1881.

the strata up to the millet-seed ironstone as Corallian, and it is in placing a division-line in the beds above this that one's decision becomes a more arbitrary matter. Partly guided by the position of the ironstone, we have endeavoured to give a position to the boundary-line above it as nearly approximate as possible to that chosen at Dover.

The fossils of the limestone do not call for any special remark and are of exactly the same facies as in the corresponding beds at Dover. The same may be said of the Lower Corallian clays, which here also form a continuous series with the underlying Oxford Clay without showing any sudden or marked lithological change, except for a subsidiary calcareous band at the base. There is good evidence for the presence of the Cordatus Zone in the lower beds. In agreement with the plan adopted in the case of the Dover section, we must put the base of the Corallian Series below this zone, and, as might be expected, the evidence for the precise position of a dividing line between the lowest Corallian strata and the underlying Mariae Beds of the Oxford Clay is no more satisfactory than at Dover. The remarks on the correlation of the Corallian rocks of Dover, which we made when dealing with the fossils from that section, apply also to Brabourne.

(1.) *Fossils from the Upper Corallian Beds; depth*, 973 *feet to* 1,135 *feet.*

Depth in feet.	
1,009, 1,040, [1,078—1,100]	Serpula sp.
990	Lingula ovalis *J. Sow.*
[1,035—1,044]	Ornithella sp.
[1,016—1,034], [1,045—1,058]	Rhynchonella sp.
[1,035—1,044], [1,100—1,134]	Terebratula sp.
[1,045—1,058]	Arca *cf.* aemula *Phill.*
[1,016—1,034]	Astarte sp.
[983—992], 1,010, [1,035—1,044], [1,045—1,058], 1,065	Exogyra nana (*J. Sow.*)
[993—995], [996—1,008]	„ *aff.* virgula (*Defr.*)
973	Gervillia kimmeridgensis *d'Orb.* [top bed only]
[973—982]	Gervillia sp.
[1,060—1,077]	Lucina rugosa ? *d'Orb.*
1,109	Mytilus subpectinatus *d'Orb.*
[993—995]	Nucula sp. [? *cf.* menkei *F. A. Roem.*]
[973—982], [1,016—1,034], [1,078—1,100], [1,100—1,134]	Ostrea sp.
[973—982]	Pecten (Syncyclonema) demissus *Phill.*
[1,078—1,100]	„ (Chlamys) fibrosus *J. Sow.*
[983—992], 993, [996—1,008], 1,010, [1,010—1,015], [1,060—1,077], [1,078—1,100]	„ „ *cf.* kimmeridgensis *Cott.*
[994], [1,060—1,077]	Pinna sp.
[1,078—1,100]	Pleuromya sp.
[1,016—1,034], [1,060—1,077]	Protocardia sp.
[1,016—1,034]	Trigonia irregularis *Seebach*
1,081	„ *cf.* voltzi *Ag.*
[1,078—1,100]	Alaria ?
[1,060—1,077]	Perisphinctes sp.

The assemblage of fossils found here above the ironstone (which occurs at a depth of 995 feet), while showing good general agreement with that obtained from the corresponding beds at Dover, includes also some well-marked forms which were not collected

there. Thus, the downward range of *Pecten* (*Chlamys*) cf. *kimmeridgensis*, which was found in the lower part of the Virgula Beds, is extended to a considerable distance below the iron ore. There occur also both above and below the ironstone a few specimens of an *Exogyra* with curved, striated valve, closely resembling *E. virgula*; these, however, are not the large valves of typical aspect such as were met with in the Virgula Beds above, though they are probably related forerunners. *Gervillia kimmeridgensis*, which we have found to characterise the Virgula Beds, was seen here only in the uppermost part of the strata we have classed as Upper Corallian.

It may be said that, just as at Dover, the lamellibranch-fauna from above the Corallian Limestone differs chiefly from that of the lowest Kimmeridge beds by the prevalence of *Exogyra* of the *E. nana* type. *Mytilus subpectinatus* was only found below a depth of 1,100 feet.

The *Ornithella* in the above list is represented by one specimen from a depth of about 1,040 feet, that is to say, about 45 feet below the ironstone. It may possibly be related closely to the species represented at Dover about 30 feet above the ironstone, though more likely this is not the case, as it appears to belong to a broader form than the Dover examples. The Brabourne specimen is small (length 14 mm.; breadth 12 mm.) and shows a flatness of the valves and a receding character of the beak which are features of immaturity, and a comparison is therefore difficult.

(2.) *Fossils from the Corallian Limestones; depth*, 1,135 *feet to* 1,269 *feet.*

Depth in feet.	
[1,136—1,138]	Cladophyllia ?
[1,221—1,257]	Isastraea explanata ? (*Goldf.*)
[1,136—1,138], [1,181—1,201]	Thamnastraea arachnoides (*Park.*)
1,179, [1,221—1,257]	„ concinna (*Goldf.*)
1,179 to base.	„ sp.
1,235, 1,255	Traces of corals, indet.
1,136—1,267	Cidaris florigemma *Phill.* [spines]
[1,221—1,257]	Rhynchonella sp.
[1,258—1,267]	Terebratula sp.
1,263	Lima (Plagiostoma) rigida ? *J. Sow.*
[1,221—1,257]	Lithodomus inclusus (*Phill.*)
[1,136—1,138], 1,179, [1,181—1,201]	Ostrea sp.
[1,181—1,201], 1,263, [1,258—1,267]	Pecten (Chlamys) vimineus *J. de C. Sow.*
Various depths.	„ spp.
[1,136—1,138]	Nerinea sp.
„	Pleurotomaria reticulata *J. Sow.*
„	Gasteropods, indet.
[1,213—1,220], [1,258—1,267]	Crustacean

The limestones here do not fall readily into two distinct masses showing lithological and palæontological differences as at Dover, but an impure and marly character only became apparent at the very base. The fauna is essentially the same as that seen at Dover. One misses here the abundant and massive shells of *Nerinea* which occurred in the upper limestone at Dover, but this is doubtless only an apparent absence due to the disadvantage of having only a boring-core from which to collect. The corals here, as at Dover, are replaced by coarsely crystalline calcite with

all the structural features usually obliterated, except occasional traces of the septal plan at the calicinal surface.

With the material at hand no attempt can be made to show any restriction of distribution among the species within the whole thickness of the limestones; but it may be noted that *Cidaris florigemma* was seen to occur throughout the whole limestone series.

(3.) *Fossils from the Lower Corallian Beds; depth, from* 1,269 *feet to about* 1,315 *feet.*

Depth in feet.	
Various depths	Serpula sp.
[1,292—1,301]	Rhynchonella varians (*Schloth.*)
[1,292—1,301], 1,311	,, ,, ?
[1,292—1,301]	Terebratula *cf.* andelotensis *Haas*
1,311	,, sp.
[1,282—1,291], [1,292—1,301]	Cucullaea sp.
[1,269—1,281]	Gryphaea sp.
[1,292—1,301]	Modiola bipartita *J. Sow.*
[1,282—1,291], 1,285, 1,290	Ostrea (Alectryonia) gregaria *J. Sow.*
1,285	Ostrea sp. [large and smooth]
[1,269—1,281]	Perna sp.
[1,269—1,281], 1,290	Pholadomya sp.
[1,282—1,291]	Pecten (Chlamys) vimineus *J. de C. Sow.*
[1,292—1,301]	Pleuromya recurva ? (*Phill.*)
[1,269—1,281]	Trigonia sp. [clavellate]
[1,292—1,301]	Cardioceras *cf.* cordatum (*J. Sow.*)
[1,282—1,291], [1,292—1,301]	,, tenuicostatum ? (*Nik.*)
[1,292—1,301]	,, sp.
1,311	Peltoceras williamsoni (*Phill.*)

Just as at Dover, the beds below the limestones here are essentially clayey, and at their base show no general lithological distinction by which they may be separated from the underlying Oxford Clay. No ammonites were found in the cores from a depth between 1,269 feet and 1,282 feet, but part of a valve of *Gryphaea* occurring in these top beds showed the weak umbonal incurvation and the relatively large area of apical attachment which was noted in specimens from the corresponding horizon at Dover.

Cardioceras was first met with below a depth of 1,282 feet, and specimens referred with doubt to *C. tenuicostatum* occurred both here and also between 1,292 feet and 1,301 feet, while a fragment resembling *C. cordatum* was also procured from between the last-named depths. We cannot state its precise position within these figures and doubt arises as to where the basal line of the true Cordatus Zone should be drawn. The whole of these 10 feet of strata may fall within the zone, or it is possible that the lowest few feet should be ascribed to a lower position, belonging to the basal beds of the Corallian Series; or again, the base of the zone may perhaps be at a depth below 1,302 feet. But the evidence before us is so incomplete that we cannot say exactly what thickness of Corallian beds of Pre-cordatus age may be present here.

It is accordingly difficult to give a boundary line between the base of the Corallian Series and the top of the Mariae Zone. But the presence of *Peltoceras williamsoni* at 1,311 feet may be taken to indicate that the Corallian rocks had not been passed

through at that depth, and in the absence of typical fossils of the Mariae Beds from depths between this and 1,342 feet, within which part of the section these beds must undoubtedly have their place, the base of the Corallian Series may be arbitrarily taken to be at a depth of about 1,315 feet. The boundary thus selected for the purposes of tabulation is of course an approximate and provisional one.

In contrast to the more clayey character of the bulk of the strata below the Corallian Limestone, the bed occurring at 1,311 feet is an impure, brownish, somewhat ferruginous limestone. In this band, in addition to *Peltoceras williamsoni*, were found *Serpula*, *Rhynchonella varians?* and *Terebratula*. The question naturally arises whether the downward zonal range of *Peltoceras williamsoni* is so restricted as to render this fossil useful as an indication of the Lower Corallian age of the beds at this level. Phillips's original specimen is Corallian, and examples from the Lower Calcareous Grit are well known in public collections. We cannot ascertain that this species has ever been found so low as the Mariae Zone, and Mr. Buckman thinks we may regard its Corallian age to be well established.

Oxford Clay.

Although the evidence obtained from the cores of this boring does not enable us to trace palæontologically the downward passage from the Corallian Series to the Oxford Clay with any greater precision than at Dover, yet it is certain that the highest zone of the Oxford Clay, the Mariae Beds, must fall somewhere between depths of about 1,315 feet and 1,340 feet. As already stated, it is merely a question how many feet of the beds below 1,311 feet must be classed as the lowest Corallian strata. We have seen that unmistakable fossils of the Cordatus Beds occur down to about 1,300 feet, and it is probable that the underlying "pre-*cordatus*" strata of Mr. Buckman's zonal scheme occupy a position between this and perhaps a few feet below 1,311 feet, where *Peltoceras williamsoni* was found.

If the upper limit of the Mariae Beds at this locality cannot therefore be precisely fixed, the evidence for their lower limit is at any rate more satisfactory, for the strata between 1,342 feet and 1,430 feet yield some of the species which characterised the underlying Renggeri Beds at Dover. Without the positive evidence of critical fossils themselves, it can therefore safely be inferred that the Mariae Beds are only represented at the most by about 27 feet of strata, and possibly by somewhat less. It will be remembered that at Dover about 30 feet of clays could be assigned to this zone. There is therefore no evidence for any marked disparity in the thickness of this zone at Dover and at Brabourne; but in the case of the underlying zone, the Renggeri Beds, to which, at Dover, we were led to ascribe a thickness of about 45 feet, there is an increase to about 88 feet in thickness at Brabourne.

With regard to the underlying beds of the Ornatus Zone, which were only 13 feet thick at Dover, the westerly expansion is seen to be more marked, for at Brabourne we find nearly 60 feet of

strata which agree remarkably closely with the thin series at Dover with which we correlate them. Here, as at Dover, the great abundance of *Cucullaea* and *Grammatodon* preserved as casts and moulds of a brown colour is a marked feature, and the agreement in lithological characters also is so very close that were specimens from the two localities to be mingled, it would be impossible to separate them except by their labels. In both cases the clay of the Ornatus Zone is harder, more impure and sandy and more coarse-grained than that of the overlying zone.

(1.) *Fossils from the Zone of* Quenstedtoceras mariae; *depth, from about* 1,315 *feet to* 1,342 *feet.*

The few fossils obtained from this part of the series are of a very unsatisfactory nature. No characteristic species of the Mariae Beds were found in the core between the above-mentioned depths, and although some of the following no doubt came from here, no record of their exact position between 1,302 feet and 1,342 feet was obtained. Some of them may therefore belong to the lowest Corallian beds, above 1,315 feet.

Plant traces
Ostrea sp.
Pleurompa sp.
Pinna *cf.* mitis *Phill.*
Alaria sp.
Cerithium?
Oppelia?
Perisphinctes *cf.* subtilis *Neum.*

The absence of species of *Quenstedtoceras* such as *Q. mariae* and *Q. lamberti* may be reasonably ascribed to the chances which attend the gathering of evidence from a boring-core of relatively narrow diameter, for these leading fossils were found in the corresponding beds at Dover. As explained above, the assignment of these beds at Brabourne to the Mariae Zone must rest chiefly upon the character of the fossils in the strata immediately above and below.

(2.) *Fossils from the Zone of* Creniceras renggeri; *depth,* 1,342 *feet to* 1,430 *feet.*

Depth in feet.	
[1,361—1,382]	Anomia sp.
"	Grammatodon concinnus (*Phill.*)
[1,342—1,360]	Gryphaea sp.
"	Nucula ornata? *Quenst.*
[1,361—1,382]	Pinna mitis *Phill.*
[1,342—1,360], [1,361—1,382]	Alaria trifida? (*Phill.*)
[1,342—1,360]	Cerithium?
[1,411—1,429]	Hecticoceras *cf.* punctatum (*Stahl*)
[1,361—1,382]	Lunuloceras? lævigatum (*Rein.*)
1,355	Perisphinctes alligatus? (*Leck.*)
"	" birmensdorfensis? (*Moesch*)
[1,342—1,360]	" *cf.* gleimi (*Steinm.*) *Par. and Bon*
[1,411—1,429]	" sp.
"	Quenstedtoceras lamberti (*J. Sow.*)
"	" *aff.* " "
[1,342—1,360]	" macrum (*Quenst.*)
[1,342—1,360], [1,382—1,409]	Taramelliceras sp.
1,355, [1,361—1,382]	Belemnites sp.
[1,342—1,360]	Crustacean remains

It will be noticed that this assemblage, taken as a whole, compares very closely with that from the corresponding part of the Oxford Clay in the Dover section.

(3.) *Fossils from the Ornatus Zone; depth,* 1,430 *feet to* 1,488 *feet.*

Depth in feet.	
[1,451—1,470]	Serpula vertebralis *J. de C. Sow.*
[1,430—1,450]	Webbina sp.
,,	Rhynchonella varians (*Schloth.*)
[1,451—1,470]	Terebratula sp.
[1,471—1,487]	Astarte *cf.* carinata *Phill.*
1,449, [1,430—1,450] [1,451—1,470], [1,471—1,487]	Cucullaea *cf.* subtetragona (*Morr.*)
[1,471—1,487]	,, sp. (A)
,,	Eopecten velatus (*Goldf.*) [Velopecten]
,,	Grammatodon *cf.* concinnus (*Phill.*)
,,	,, sp. (A)
,,	Gryphæa sp.
,,	Lucina?
,,	Modiola bipartita *J. Sow.*
[1,451—1,470]	Nuculana phillipsi (*Morr.*)
[1,471—1,487]	Pecten (Chlamys) fibrosus *J. Sow.*
[1,451—1,470]	,, sp.
[1,471—1,487]	Protocardia striatula (*J. de C. Sow.*)
,,	Pteria (Oxytoma) inequivalvis (*J. Sow.*)
[1,430—1,450]	Thracia depressa? (*J. de C. Sow.*)
[1,471—1,487]	Trigonia sp. [fragment of a clavellate species]
[1,430–1,450]	Spinigera sp.
[1,471—1,487]	Cosmoceras gulielmi (*J. Sow.*)
,,	,, jason? (*Rein.*)
[1,451—1,470]	Perisphinctes?
[1,471—1,487]	Belemnites sp. [fragments]

Compared with the higher zones of the Oxford Clay, the cores from this part of the boring were found to be more richly fossiliferous. The comparison of the above list with that of the fossils obtained in the lowest 13 feet of Oxford Clay at Dover shows close agreement. Not only are the ammonites those which are associated to characterise the zone of *Cosmoceras ornatum*, but the lamellibranch-fauna, containing an assemblage of species of *Cucullaea* and *Grammatodon*, would alone furnish very strong evidence of contemporaneity. These two genera are represented by so many individuals that they may be regarded as the dominant forms. We have remarked above that their mode of preservation at the two localities is identical, but amongst the material from Brabourne there occur specimens which display their characters more perfectly than any collected at Dover, and hence they may be briefly described in this place.

One species of *Cucullaea* occurs here in some bands in great profusion. It is most common in the upper 40 feet, but appears to be very sparingly represented in the lowest 16 feet. In the above list this is named *Cucullaea* cf. *subtetragona* Morr. It closely resembles *C. subtetragona* (of the Kellaways Rock and Lower Oxford Clay)[1] in its shape and its predominating concentric ornaments, but differs from it by the absence of radial ribs at the

[1] J. Morris. 'List of Organic Remains . . . .' *Quart. Journ. Geol. Soc.*, vol. vi., 1850, p. 318, pl. xxx., fig. 5 [as *Arca*].

anterior and posterior ends. Considerable resemblance is also shown to *Cucullaea roederi* de Lor.[1], which occurs in the so-called "Middle Oxfordian" of the Bernese Jura, but the Swiss species is distinguished by a somewhat more oblique figure, a shorter hinge-line, and the presence of delicate radial ribs anteriorly and posteriorly.

Another form of *Cucullaea*, which was only found in the lowest 16 feet of this zone at Brabourne, is also characterised by concentric ornamentation, but it has a more elongated outline. It is named *Cucullaea sp.* (A) in the above list. It agrees almost exactly in shape with *Grammatodon alsatica* (Roeder)[2] from the "Middle Oxfordian" in the Bernese Jura, in which, also, the predominant sculpture is concentric. But the Kentish specimens, which are indifferently preserved, show no trace of radial ornaments towards the anterior and posterior extremities, and they probably represent a true *Cucullaea*, to judge from traces of the posterior hinge-teeth which can be seen.

Of the two species of *Grammatodon* observed to occur here, one is an elongated form with oblique inequilateral figure. It bears an ornamentation of radial ribs which are well developed on the posterior area and become very weak or evanescent at the middle of the valve. On the anterior surface of the valve there are a few more salient and more widely-spaced radiating ribs. This we have named *Grammatodon* cf. *concinnus* (Phill.). The available specimens are not many in number and are unsatisfactorily preserved, but they appear to show close agreement with Phillips's type, in the York Museum, which has been well figured by de Loriol[3], and with figures of specimens which occur in the "Lower" and "Middle Oxfordian" of the Bernese Jura, referred to the English form by the same author[4]. We have seen that this species occurs in higher zones of the Oxford Clay, here and at Dover. The other form, named *Grammatodon sp.* (A) in the foregoing list, has greater height in relation to length, and is less inequilateral. The posterior area is well demarcated, and the whole surface of the valve is ornamented by impressed radial linear striæ showing a punctate structure. A specimen measures 23 mm. in length and 13 mm. in height, measured at the umbo. The same form is known to occur at Chippenham (? in the lowest Oxford Clay), and most probably it represents an undescribed species. At Brabourne it was only found in the lowest 16 feet of this zone.

No evidence was obtained here for the presence of a thin, dark, shelly bed at the base, such as was met with at Dover. Although the existence of such a bed might easily escape observation in the

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[1] P. de Loriol. 'Étude sur les Mollusques et Brachiopodes de l'Oxfordien supérieur et moyen du Jura Bernois,' Suppl. 1, p. 79, pl. v., figs. 7–10. *Mém. Soc. Pal. Suisse*, vol. xxviii., 1901.

[2] P. de Loriol, *op. cit.*, p. 82, pl. v., fig. 11.

[3] P. de Loriol. 'Étude sur les Mollusques et Brachiopodes de l'Oxfordien supérieur et moyen du Jura Bernois,' pl. xiv., fig. 10. *Mém. Soc. Pal. Suisse*, vol. xxiv., 1897.

[4] *Ibid.*, figs. 5–9.

boring core, it is not improbable that it is really absent here and is represented by strata of the normal type which make up the bulk of the zone as developed here and at Dover. The disparity in thickness of a series so wonderfully similar, both lithologically and palæontologically, at Dover and Brabourne, may perhaps be partly accounted for by the differences in local conditions of deposition at the time represented by the lowest part of the Ornatus Beds. The basal shelly band at Dover may well represent a period of locally slow accumulation on a floor exposed to currents, while the contemporaneous deposition at Brabourne proceeded under quieter and more uniform conditions, which permitted steady accumulation of the type seen later to have taken place at Dover also.

Strata between the Oxford Clay and the Lias.

(1.) *Fossils from the Kellaways Rock; depth, about* 1,488 *feet to* 1,506 *feet.*

Depth in feet.	
[1,488—1,502]	Lingula sp.
,,	Eopecten velatus (*Goldf.*) [Velopecten]
,,	Gryphaea bilobata *J. de C. Sow.*
,,	,, sp. (A)
,,	Pecten *cf.* vagans *J. de C. Sow.*
[1,504]	Pseudomonotis sp. [? sp. nov.]
1,490, 1,504	Pteria (Oxytoma) inequivalvis (*J. Sow.*)
[1,488—1,502]	Unicardium sp.
1,490	Belemnites sp.

The above small assemblage yielded by the core from the beds we have classified as Kellaways is quite comparable in character with the fauna from the corresponding beds at Dover. Both the species of *Gryphaea* found at Dover occur here also; and so far as its characters can be compared, an imperfectly preserved left valve of *Pseudomonotis* may well be identical with the undescribed species noted at Dover from this horizon. It may also be mentioned that the remains of belemnites were found here in the cores from the upper beds, but not in the lower part, and this is reminiscent of the distribution observed at Dover, where, in the strata assigned to the Kellaways Rock, belemnites were of frequent occurrence, except in the lowest beds. There is no evidence here for the presence of the indurated bed at the very top, containing an abundance of *Pseudomonotis sp. nov.*, which was seen at Dover, and we may conclude that it was of local extent, perhaps forming merely a shelly lenticle.

Cornbrash.

The definite assignment to the Cornbrash of any portion of the beds in this section is a matter of difficulty, as explained in a previous chapter. It is possible that the Cornbrash is here extremely thinly represented, and that its local equivalent may be included at the base of the strata which we have classed as Kellaways. Unfortunately we obtain no help from palæontological evidence.

(2.) *Fossils from the Forest Marble; depth,* 1,506 *feet to* 1,519 *feet.*

No specifically determinable fossils were brought up from the beds provisionally assigned to this division, and the few remains that were obtained comprise only Pentacrinine columnals, *Serpula, Terebratula* and *Lucina?*. The *Terebratula* is known only from a ventral valve of fairly convex form, with narrowed beak-region and well-marked biplication occupying rather more than the anterior third of the valve.

(3.) *Fossils from the Great Oolite Limestones; depth,* 1,519 *feet to* 1,633 *feet.*

Depth in feet.	
1,518, [1,579—1,598]	Pentacrinine columnals
[1,551—1,568]	Echinoid spine [fragment]
[1,569—1,578], 1,602	Rhynchonella sp.
[1,579—1,598]	Terebratula sp.
[1,551—1,568]	Corbula buckmani *Lycett*
[1,609—1,632]	Eopecten sp.
[1,579—1,598]	Gervillia sp.
[1,551—1,568]	Lima (Limea) duplicata (*J. de C. Sow.*)
„	Nuculana lachryma (*J. de C. Sow.*)
„	Ostrea rugosa ? *Goldf.*
[1,579—1,598]	„ sp.
[1,609—1,632]	Pecten (Camptonectes) lens *J. Sow.*
[1,599—1,608]	„ (Chlamys) retiferus *Morr. and Lyc.*
[1,609—1,632]	Placunopsis jurensis (*F. A. Roem.*) [Lycett's reading]
[1,519—1,550]	„ socialis *Morr. and Lyc.*
[1,609—1,632]	Pseudomonotis echinatus (*J. Sow.*)
1,630	Trigonia sp. [costate]
[1,579—1,598]	Nerinea ?

The above list includes a typical assemblage of Great Oolite lamellibranchs which call for no special remark. The specimens of *Terebratula* and *Rhynchonella* were unfortunately too immature or too fragmentary to permit of definite identification. Several of the above species, such as *Pecten retiferus, Placunopsis jurensis* and *Pseudomonotis echinatus*, occurred in the oolitic limestone from below 1,600 feet, and down to a depth of 1,633 feet there was no sign of any change which could shake our confidence in ascribing at least 114 feet of beds to the Great Oolite. It will be noticed that the chances of collection from material obtained by means of boring and sinking have given us lists of species from Dover and Brabourne which differ from one another in many respects; but both lists have the same geological significance, and one must be considered to supplement the other in making up the sum of our knowledge of the fauna from the Great Oolite in Kent.

(4.) *Strata between the Great Oolite Limestone and the Lias; depth,* 1,633 *feet to* 1,700 *feet.*

The dark calcareous shales and the basal limestone, forming the lowest part of the Oolitic Series preserved at this locality, showed only the most scanty remains of fossils in the cores, and nothing was obtained which is of help in determining the position

of any bed. The shales, which here and there contained small fragments and traces of lignite, yielded only a few scattered remnants of lamellibranch-shells such as *Pteria* (*Oxytoma*) *inequivalvis* (J. Sow.) and *P. costata* (J. Sow.), *Astarte* of a small and coarsely-ribbed species, *Lima*, *Gervillia?* and *Pholadomya?* Although in these shales we see an approach to a Fullonian lithological facies, in the absence of palæontological evidence it is impossible to speak with certainty regarding their correlation and that of the underlying limestone. It seems, however, not improbable that this limestone may be of Inferior Oolite age, and it rests unconformably upon a bed in the Upper Lias belonging to a higher zone than the uppermost Lias at Dover. There is a very marked hiatus in the series here, though the gap in time which it represents is, no doubt, less than at the corresponding part of the sequence at Dover.

Lias.

In the following notes the names of the broader zonal divisions are used in the sense employed by Mr. H. B. Woodward[1].

(1.) *Fossils from the Upper Lias; depth,* 1,700 *feet to* 1,715 *feet.*

Depth in feet.	
1,715	Inoceramus sp.
[1,701—1,713]	Gasteropod
1,715	Dactylioceras commune ? (*J. Sow.*)
[?] 1,714	* Grammoceras *cf.* striatulum (*J. de C. Sow.*)
[1,701—1,713]	Hildoceras walcotti (*J. Sow.*)
1,714—1,715, 1,715	
1,714—1,715	Peronoceras attenuatum (*Simpson*)
[?] 1,714	* Pseudogrammoceras ?

* Occurring in the same hand-specimen.

The cores from the 15 feet of Upper Lias in this boring fortunately furnished some of those very remains of ammonites which are best fitted to give a precise indication of the zonal position. As named by Mr. Buckman, these show that the fauna of the Communis Zone (which includes the Bifrons Zone of Mr. Buckman's classification) is well represented. The above species of *Dactylioceras*, *Hildoceras* and *Peronoceras* indicate a Bifrons fauna, but it must be inferred from the occurrence of *Grammoceras* cf. *striatulum*—which is ascribed by Mr. Buckman to his Striatulus Zone—that the overlying Jurensis Zone is also represented. This specimen was obtained from a part of the core marked as occurring within two feet of the base of the Upper Lias, where it would be associated with the Bifrons fauna. But it is most probable that there has been an error, perhaps due to the reversal of a few feet of the core when it was placed in storage, and that this specimen in reality comes from a slightly higher level.

The specimens characterising the Bifrons Zone (the lower part of the Communis Zone) are recorded as occurring down to within

[1] H. B. Woodward. 'The Jurassic Rocks of Britain,' vol. iii. (*Mem. Geol. Surv.*), 1893 p. 34, ["General Grouping"].

a foot of the base of the Upper Lias, and no palæontological evidence was obtained for the presence of the underlying Serpentinus Zone, to which, it may be remembered, belongs the uppermost bed of the Lias at Dover and Ropersole. It is possible that at Brabourne this may be represented by only a few inches of rock, in which case the absence of characteristic fossils within the limited diameter of the core would not be surprising. But it is also conceivable that the conditions were such that practically no accumulation of sediments could take place here at that particular time, and the zone might really be unrepresented without there being evidence of a marked break or a hiatus in the sequence such as would be expressed by an actual unconformity.

(2.) *Fossils from the Middle Lias; depth,* 1,715 *feet to* 1,760 *feet.*

(a). Depth, 1,715 feet to 1,745 feet.

Depth in feet.	
[1,716—1 728], [1,729—1,736]	Rhynchonella capitulata *Tate*
" "	" tetrahedra (*J. Sow.*)
1,725	" sp.
[1,737—1,745]	Pecten (Chlamys) calvus? *Goldf.*
[1,716—1,728]	" (Pseudopecten) aequivalvis *J. Sow.*
[1,716—1,728], [1,729—1,736]	" (Syncyclonema) liasianus *Nyst*
[1,729—1,736]	Pseudomonotis *cf.* substriatus (*Münst.*)
"	" sp. nov.
[1,737—1,745]	Pteria (Oxytoma) sp.
1,735	Belemnites?

Remains of ammonites were unfortunately not met with in the cores from the Middle Lias; and from between the depths last mentioned it was only possible to secure examples of the above representatives of a fauna which, though rich in individuals, appears relatively poor in the number of species. At the same time it should be realised that an estimate of the actual richness in species cannot with safety be made from the examination of a core of relatively narrow diameter, such as the one with which we are dealing.

Rhynchonella capitulata, found here at depths between 1,716 feet and 1,736 feet, is elsewhere known as a characteristic fossil of the Spinatus Zone, the higher of the two zones of the Middle Lias. In the core from about 1,730 feet, in a band of hard, grey, shelly limestone, two distinct species of *Pseudomonotis,* represented by left valves, were recognised. One, which we have brought into comparison with *Pseudomonotis substriatus* (Münst.), is certainly not identical with that species. There is considerable similarity in shape, but the Brabourne shell has a slightly less oblique figure, and it is less delicately and less densely ribbed. It may probably belong to an undescribed form. The other species seems also to be new. It is characterised by very moderate convexity and nearly equilateral figure, but above all by its sculpture. This consists of very closely-spaced, narrow, rounded, radiating ribs, with narrower linear interspaces. Coarser and finer ribs frequently alternate with regularity, while new ribs, at first weak and delicate, are added by intercalation at various points on the surface.

Below the level where the above two fossils were found, there occurred in the shelly limestone some small examples of an *Oxytoma*, which measure less than 10 mm. in height. Only the left valves have been seen, and these are marked by strong convexity and an ornamentation of relatively strong, well-spaced radiating ribs. They may be immature specimens of one of the known examples of the group of *Pteria* (*Oxytoma*) *inequivalvis* (J. Sow.), or they may possibly represent some hitherto undescribed form. The rock which contains these little fossils is a hard and compact, partly crystalline limestone, crowded with shell-fragments. No similar clear water deposit was noted in the cores from the corresponding horizon at Dover.

From the evidence obtained it is not possible to say what thickness of strata below 1,716 feet should be assigned to the Spinatus Zone, but some figure between 20 feet and 30 feet may be suggested.

(b). Depth, 1,746 feet to 1,760 feet.

Depth in feet.	
[1,754—1,758]	Wood
[1,746—1,750]	Ditrupa sp.
[1,754—1,758]	Rhynchonella sp.
1,756	Cardinia sp.
[1,746—1,750]	Grammatodon sp. (B)
,,	,, sp. (C)
,,	Lima *cf.* pectinoides *J. Sow.*
1,749	,, sp.
[1,754—1,758]	Modiola scalprum *J. Sow.*
1,749	,, sp.
1,756	Myoconcha decorata (*Münst.*)
[1,746—1,750]	Nuculana sp. (A)
,,	Pecten (Pseudopecten) aequivalvis *J. Sow.*
,,	,, (Chlamys) *cf.* dentatus *J. de C. Sow.*
1,752	,, (Syncyclonema) liasianus *Nyst*
[1,746–1,750]	Pinna sp.
,,	Protocardia truncata (*J. de C. Sow.*)
,,	Unicardium cardioides ? (*Phill.*)
[1,754—1,758]	Lamellibranchs [of several doubtful genera]

In these lower beds of the Middle Lias, fossils were found to be abundant, but again there is a relative paucity of species and an unfortunate absence of ammonite-remains. The dark greenish-blue micaceous shale entered at a depth of 1,746 feet is crowded with lamellibranchs, mostly preserved as casts, and one of these is of some interest in relation to the question of zonal position. This is *Nuculana sp.* (A) of our list, a well-characterised form represented by an example measuring nearly 20 mm. in length and having a rounded frontal profile and bluntly pointed posterior extremity. The umbo has little prominence, and is situated at a distance of one-third of the shell's total length from the anterior end. The height of the valve, measured at the umbo, is about 8 mm. The posterior cardinal margin is long and straight, sloping down very gradually from the umbo, and the inferior margin slopes up posteriorly in a regular curve to approach the cardinal margin finally at right angles at the posterior extremity. The surface is ornamented by a series of upwardly imbricating concentric bands or ridges, most markedly developed in the lower half of the valve.

Specimens of a *Nuculana* showing so exact an agreement of characters with this shell as to be indistinguishable from it occur in the Middle Lias with *Amaltheus margaritatus* Montf. near Lincoln and Grantham, and have been exhibited under the name *Nuculana quenstedti* (Tate) in the Museum of Practical Geology. This reference to Tate's species, a form which occurs in zones of the Lower Lias of Antrim, is no doubt incorrect. There is some similarity in shape, but the Irish species has a more angular hinge-line, and appears to differ further by minor characters of shape and by the absence of imbricating ornaments. The exact vertical distribution of *Nuculana sp.* (A) is not known, but it is not improbable that the zonal range of a species so well characterised was a fairly restricted one, and its occurrence here may perhaps be taken as some indication that beds of the Margaritatus Zone had been entered.

In the same bed of micaceous clay there occurred two forms of *Grammatodon*, preserved only as casts, which we have been unable to identify. One, species (B) of our list, is characterised by greater height at the frontal border than at the posterior margin, and there are traces of fine radial ribbing on the posterior area and also on the anterior part of the valve. An apparently distinct form, species (C), is represented by a single example which is somewhat less equilateral than the last. It appears to be more elongated posteriorly and to have relatively less height anteriorly. Definite traces of ribbing cannot be seen on this specimen.

Amongst the fossils from the brown ferruginous limestone occurring a few feet lower down, in addition to *Modiola scalprum* and *Myoconcha decorata* are specimens of *Cardinia*, which are preserved as casts and bear impressions of the flattened imbricating ridges which characterise most species of this genus. The valve is relatively elongated in shape, with the umbo well advanced towards the anterior end. Specific identification is made difficult by the indifferent preservation, and it must suffice to note the occurrence of this form and to observe that it is somewhat reminiscent of elongated examples of *Cardinia listeri* (J. Sow.) from the Lower Lias; for instance, the so-called variety *ovalis* Stutchbury. It is distinguished from these by its more depressed and elongated outline and its more inequilateral character. It is less elongated than *Cardiana concinna* (J. Sow.), and differs further in having a much less convex inferior border.

(3.) *Fossils from the Lower Lias; depth,* 1,760 *feet to* 1,840 *feet.*

(a). Depth, 1,760 feet to 1,820 feet.

Depth in feet.	
[1815—1817]	Plant traces
[1770—1799], 1,805—1,820	Pentacrinine columnals and cirri
[1,815—1,817]	Orbiculoidea sp.
1,818	Rhynchonella curviceps? (*Quenst.*)
[1,815—1,817], 1,818	„ *cf.* rostellata (*Quenst.*)
1,809, [1,815—1,818]	„ spp.
1,769	Astarte *cf.* irregularis *Terq.*
[1,770—1,799]	„ sp. (A)
[1,815—1,817], 1818	„ sp. (B)

Depth in feet.	
[1,770—1,799]	Gervillia sp.
"	Goniomya hybrida ? (*Münst.*)
[1,770—1,799], [1,819—1,820]	Grammatodon intermedius (*Simpson*)
1,818	Lima sp.
[1,815—1,817], [1,819—1,820]	Lucina ?
1,818	Myoconcha decorata (*Münst.*)
1,788	Nucula sp.
[1,770—1,799], [1,800—1,814], [1,815—1,817], 1,818	Nuculana sp. (B)
[1,770—1,799]	Pecten (Syncyclonema) sp.
1,818	„ (Chlamys) sp.
"	Unicardium ?
"	Liparoceras maculatum (*Young and Bird*)
[1,800—1,814], [1,815—1,817]	„ arcigerens ? (*Phill.*)
1,818	„ sp. [fragment of bispined form]
[1,770—1,799]	„ sp.
[1,815—1,817]	? Polymorphites trivialis (*Simpson*)
1,818, 1,820	Belemnites sp.

Fossils were not obtained from the uppermost 10 feet of the grey clays which constitute the upper 60 feet of Lower Lias in this boring. Both in the character of these clays and the mode of preservation of the fossils, very close agreement is shown with the lowest four feet of Lias at Dover, which contained a fauna ascribable to the upper part of the Capricornus Zone. At Brabourne the evidence does not suffice to enable us to fix precisely the upward limit of this zone on purely palæontological grounds, but in all probability it should not be placed below a depth of 1,760 feet. In other words, a considerable part of the uppermost 60 feet of Lower Lias at Brabourne may be regarded as the greatly expanded equivalent of the basal clay at Dover.

It is, of course, not possible to say how far this appearance of westerly expansion may be exaggerated by the absence of part of the Capricornus Zone (in Mr. Buckman's restricted sense) at the base of the Lias at Dover, but it is certain that the Striatus Zone of Mr. Buckman's classification (that is, the lower part of the Capricornus Zone in Mr. H. B. Woodward's sense) is missing there. The characterising ammonite at Dover, *Liparoceras maculatum*, occurred at Brabourne down to about 1,818 feet, but the clay below this, approaching a depth of 1,820 feet, certainly represents a horizon lower than that of the basal clay at Dover. Mr. Buckman ascribes to the specimens he has named *Liparoceras arcigerens?* a rather greater possible downward range in the Capricornus Beds than to *L. maculatum*, and moreover he believes that another ammonite, *?Polymorphites trivialis*, which is here associated with *Rhynchonella* cf. *rostellata*, indicates the presence of part of the underlying Jamesoni Zone. These ammonites were not seen in the lowest bed at Dover, and the associated *Rhynchonella* which occurred in great numbers at Brabourne was also not met with at Dover.

Although the depths marked on the specimens collected from the cores are such that a downward range to a depth of 1,818 feet is ascribed to *Liparaceras maculatum*, yet the other species mentioned above, which point to a still lower palæontological horizon, were noted as occurring in the core from above 1,817 feet. It is, therefore, possible that some little error has arisen here, owing

perhaps to the reversal of a few feet of core on the storage-floor. If it be correct that *Liparoceras maculatum* occurred down to a depth of 1,818 feet, it must be inferred that nearly 60 feet of clay belong to the Capricornus Zone, and that the underlying Jamesoni Zone is represented in the lowest two feet. If, however, an error in recording the depths has occurred, it is possible that the lower zone may be represented by a few more feet of the clay.

The Capricornus Beds are here characterised by the abundant occurrence of a species of *Nuculana*, species (B) of our list, which is readily distinguished from the Middle Lias form already referred to as "species (A)." There is some general resemblance in shape, but species (B) is more inequilateral, more convex in form, and shows only lines of growth upon its surface and no imbricating ornaments. All the specimens seen are of smaller size, and the largest do not exceed 10 mm. in length. This shell may be most aptly compared with *Nuculana quenstedti* (Tate), which occurs in lower horizons of the Lower Lias in Co. Antrim. Tate gave an unsatisfactory figure and no description of his species, but his illustration[1] depicts a shell which is distinguished by larger size and more equilateral shape, and perhaps also by a less degree of convexity. It is highly probable that in species (B) we are dealing with an undescribed form, and it is one which attains importance by reason of its abundance here. Specimens were found at a depth approaching 1,800 feet, and a relatively large number occurred in the core between 1,800 feet and 1,820 feet. No example was noted from the bottom bed of Lias at Dover.

The numerous small distinctly-ribbed specimens of *Astarte* which occur in this part of the Lower Lias at Brabourne fall into three distinct species. Examples of one of these may be compared most aptly perhaps with *Astarte irregularis* Terq.[2], which occurs commonly in still lower zones of the Lower Lias in the East of France. We have accordingly named them *Astarte* cf. *irregularis*, while recognising the probability that these two forms are not identical. A shell of very similar type occurring in the top part of the Lower Lias in Yorkshire was referred by Tate to Roemer's *Astarte striato-sulcata*. A specimen which seems to agree precisely in its characters with this Brabourne shell occurs in the lowest four feet of the Lias at Dover. At Brabourne specimens of this form were found only at a depth of 1,769 feet.

Another *Astarte*, which for convenience of reference we have designated species (A), is represented by small shells, 7 mm. in length, having a more nearly sub-quadrate figure. These are ornamented by very numerous and delicate concentric ribs, and their characters of shape, with the post-median position of the umbones, recall *Astarte cingulata* Terq.[3], which occurs in lower zones of the Lower Lias in the East of France. The specimen

[1] R. Tate. 'A list of the Irish Liassic Fossils,' Appendix I. in Seventh *Ann. Rep. Belfast Nat. Field Club*, 1870, p. 19, pl. i., fig. 4.

[2] O. Terquem. 'Paléontologie de l'étage inférieur de la Formation Liasique de la Province de Luxembourg,' *Mém. Soc. Géol. France*, ser. 2, tome v., 1855, p. 294, pl. xx., fig. 5.

[3] O. Terquem, *loc. cit.*, pl. xx., fig. 6.

figured by Terquem is more inequilateral and is of considerably larger size than the examples obtained at Brabourne. Though not identical, these two forms illustrate the same general type of shell and are possibly allied. The Brabourne specimens were found at a depth between 1,770 feet and 1,800 feet, but not below this. A third species of *Astarte*, (B) of our list, which was first met with in the cores from near the base of the grey clay as the depth of 1,820 feet is approached, is also represented by individuals of small size, not exceeding 7 mm. in length. In a specimen of this length the greatest height is 5 mm. The shell has a sub-quadrate outline and slight convexity. The outline is vertically truncated posteriorly, excavated in front of the umbo, and narrowed and produced at the frontal margin. Well marked concentric ribs to the number of 12 to 15 ornament the surface. These are delicate and narrowly spaced, and cessation of rib-development takes place before full growth is attained, so that the surface near the pallial margin is marked only by growth-lines. We have not been able to identify this well-characterised shell, which may represent an undescribed species.

Other small ribbed specimens from the base of this clay may perhaps belong to still another species of *Astarte*, but the available material is too imperfect for an adequate characterisation. There is a distinct analogy between the life conditions during the deposition of these Lower Lias clays and the upper clays of the Kimmeridge Series passed through in this boring and at Penshurst, where also we have seen the fauna characterised in great measure by the frequent presence of ornate forms of *Astarte* of small dimensions.

A species which we have identified provisionally with *Grammatodon intermedius* (Simps.), taking Tate's interpretation as a guide, was also met with at Brabourne as well as in the lowest four feet of Lias at Dover. At Brabourne it occurred at depths both above and below 1,800 feet. The shell measures from 10 mm. to 15 mm. in length, and the ornaments consist of fine linear radial ribs which, crossed by numerous regular concentric lines, give rise to a delicate cancellated sculpture.

In the lowest five feet of the grey clay—that is, at a depth between 1,815 feet and 1,820 feet—there occur numerous crushed specimens of a *Rhynchonella* which, judging from the number of individuals present in the restricted area represented by the core, must have been one of the dominant fossils at this horizon. All the specimens are flattened and more or less distorted; but their chief characters can be made out fairly satisfactorily. The individuals attain a length of 8 mm. to 10 mm., and are quite smooth until the adult growth stage is well advanced, when 8 or 10 short radial ribs or plications are developed. Thus, specimens in which the plicated stage has not been reached present a very different aspect from that of others, more fully grown, in which short marginal folds are a marked feature. Owing to the invariably flattened condition of these shells it has not been possible to recognise a median fold or arching of the brachial valve, although this may well have been developed originally. A definite reference to any described species is scarcely possible with the materials

at hand, and there are several *Rhynchonellae* in the Lower Lias which show a smooth young and early adult stage and the later introduction of a plicated stage. Such, for instance, are *R. triplicata juvenis* (Quenst.), *R. oxynoti* (Quenst.), both of which occur lower down in the Lower Lias, and *R. rostellata* (Quenst.) and *R. persinuata* Rau, which are found in the upper part of the Lower Lias. Mr. Buckman, who has seen some of the specimens from Brabourne, suggests that they may be most fittingly brought into comparison with Quenstedt's *R. rostellata*. An example of that species from the Jamesoni Zone of Toddington, Gloucestershire, which Mr. Buckman has kindly presented to the Geological Survey, shows that if the Brabourne specimens were uncrushed they would bear close comparison, although even allowing for the effects of crushing their less sharp plications suggest that they are in reality not specifically identical.

Associated with this last is another species of *Rhynchonella*, represented by a few examples not exceeding 8 mm. in length, which are also crushed and flattened. The shells are ornamented by closely placed sharp ribs which radiate from the umbonal apex, but their condition is so poor as scarcely to permit of identification.

(b). Depth, 1,820 feet to 1,840 feet.

Rhynchonella *cf.* calcicosta (*Quenst.*)
,, rimosa (*v. Buch.*)
,, sp.
Spiriferina sp.
Eopecten sp. [Velopecten]
Gervillia sp.
Gryphaea?
Lima antiquata *J. Sow.*
,, sp.
Pecten (Chlamys) sp.
Perna?
Pinna sp.
Pitonnillus conicus *d'Orb.*
Belemnites sp.

The above rather scanty assemblage of fossils from the ferruginous beds underlying the grey clay does not give decisive evidence to show the zonal position of the lowest part of the Lias from which fossils were obtained at this locality. Since the basal part of the grey clay may be ascribed to the Jamesoni Zone it is probable that a portion at least of the underlying ferruginous beds falls within the same zone, and it cannot be stated that the upper part of the Oxynotus Zone (the Raricostatus Beds) is not also represented towards the base. If the specimens of *Rhynchonella* which we have referred to *R. rimosa* are correctly identified, these probably indicate a position in the Jamesoni Zone, and it is not improbable that *Lima antiquata* may be from a lower zone. But the collecting of material from these ferruginous beds was so carried out that the relative position of these specimens in the core is not known.

With regard to the specimens which we have compared with *Rhynchonella calcicosta*, a definite reference to that species is scarcely possible since the examples found here are perhaps too

delicately ribbed and appear to be further distinguished by a stronger inflation and a higher median arching of the brachial valve. A specimen from the lowest bed of the Lias at Dover, kindly submitted to us by Mr. John Gerrard, may perhaps be a well-grown individual of the same form; but the high and narrow arching of the brachial valve, abruptly separating this part of the valve from the lateral areas, is a very pronounced feature in that specimen.

The shells of *Rhynchonella* which we have referred provisionally to *R. rimosa* are very delicately ribbed, and if correctly identified, they represent an immature stage of growth—a stage previous to that in which coarse marginal plications first make their appearance. A third species of *Rhynchonella* is represented by a single example of larger size, which is unfavourably preserved for detailed comparison. It shows a wholly ribbed dorsal valve, about 18 mm. in length and in breadth, with a high median fold comprising about four ribs and with strongly receding lateral areas, each of which bears four or five coarse ribs. Its characters are reminiscent of those of *R. tetrahedra* (J. Sow.), and it may be remembered that Tate recorded that species from the Jamesoni Zone of Yorkshire. Whether the species really has such an extensive downward range or not, it is probable that Tate was referring to some such form as the one here met with.

CHAPTER XI.

THE PLUCKLEY BORING.

Wealden Series.

Owing to the method of boring, as already stated, the conditions were highly unfavourable for the recovery of fossil-remains from the uppermost 400 feet at Pluckley, and the few specimens secured from depths below this in the Weald Clay afford the merest glimpses here and there of the fresh-water life which must have characterised this great thickness of strata. Only ill-preserved casts of *Viviparus* and fragmentary fish-remains were seen from a depth between 300 feet and 400 feet from the surface. Specifically undetermined bivalves referable to *Cyrena* and occasional obscure plant-remains occurred between 580 feet and 660 feet in depth, while below this were some traces of fern-fronds (at 680 feet). This completes the list of fossils available for examination from the Weald Clay.

In the underlying series classified as Hastings Beds the same paucity of material is to be regretted. From a depth of 630 feet some indeterminable plant-remains were found, and at about 815 feet others which are referable to *Sphenopteris fittoni?* Seward and *Cycadites saportae* Seward. A scale of *Lepidotus*, probably *L. mantelli Ag.*, came from a depth of 931 feet.

Purbeck Beds.

By reason of circumstances already explained in the first part of this memoir, only the scantiest remains of fossils could be obtained from the Purbeck rocks passed through in this boring. The few traces of organisms found in the cores all represent fresh-water forms, and no remains were recovered which give evidence of brackish-water conditions as at Brabourne and Penshurst, although doubtless occurring here also. Below a depth of 1,044 feet the samples of the cores yielded no recognisable forms of life, and this barrenness is in agreement with the sparsely fossiliferous character of the lower beds of the Purbeck Series at Penshurst, as compared with the higher beds.

Fossils from the Purbeck Beds; depth 1,000 *feet to* 1,091 *feet.*

Depth in feet.	
1,006	Darwinula leguminella (*Forbes*)
,,	Cypridea ventrosa *Jones*
1,026	Cyrena ? [fragments]
1,037	Lamellibranchs [traces only]
1,044	? Cypridea dunkeri *Jones* [and other Cyprids]

The above and following lists of fossils from Pluckley are so meagre that the species are arranged in the order of their occurrence according to depth from the surface, and not in the zoological order adopted for the longer lists of fossils from the other sections described.

Portland Beds.

There is little to be said about the fossils from the Portland Beds at Pluckley, since at these lower depths also, our opportunities only allowed the most scanty collection of specimens to be made. No fossils were obtained from the uppermost 50 feet of strata. A large *Pecten* seen near the top of the series (but not collected) was probably *P. lamellosus*, and this species was also found within 10 feet of the base. *Trigonia* was associated with it near the top. As at Penshurst, the beds classed as Portlandian in this boring do not comprise strata equivalent to the Portland Sands, but must be correlated broadly with the Portland Stone Series of Dorset.

Fossils from the Portland Beds; depth 1,091 *feet to* 1,161 *feet.*

Depth in feet.	
1,140	Trigonia sp. [clavellate]
1,146	Lamellibranch fragments
1,150	Serpula sp. [convoluted]
1,153	Pecten (Camptonectes) lamellosus *J. Sow.*
,,	Serpula sp.
1,154	Trigonia sp. [clavellate]

Kimmeridge Clay.

It has been shown, in the account of the Pluckley boring already given in the first part of this memoir, that there is no sign here of unconformity between the Upper Kimmeridge and Portland Beds, as at Brabourne, but that the transition is an unbroken one. It was impossible to obtain so good or complete a series of palæontological specimens as in the case of the other sections described, but we have enough evidence to demonstrate the increase in thickness which has taken place both in the Upper Clays and in the Virgula Beds when compared with the series revealed at Brabourne.

Once more using *Modiola autissiodorensis* and *Exogyra virgula* as the principal guides, we are able to fix the junction here between the Upper Clays and the Virgula Beds with considerable precision. The lowest observed occurrence of the leading fossil of the Upper Clays was at a depth of 1,346 feet, while the highest position in which *Exogyra virgula* was seen was at 1,350 feet. No marked degree of overlap in the vertical distribution of these two forms could be proved at Brabourne, so that we may conclude that in taking the depth of 1,350 feet as the dividing line at Pluckley, we are choosing a boundary approximately equivalent to that adopted at Brabourne. The Upper Clays are therefore about 190 feet thick at Pluckley, compared with 622 feet observed for the equivalent beds at Penshurst, which is perhaps not quite their total thickness there. We have already discussed the evidence which leads us to believe that the uppermost 255 feet or so of the Upper Clays at Penshurst are unrepresented at Brabourne, where the series is incomplete in its upward extent. It may therefore be estimated that, provided the progressive

westerly thickening was evenly distributed throughout the whole thickness of the Upper Clays, the 64 feet of these beds seen at Brabourne correspond with the lowest 110 feet or so at Pluckley; that is to say, the strata between 1,240 feet and 1,350 feet in depth, which become further thickened to nearly 370 feet at Penshurst.

As the following list of fossils will show, the remnants of the fauna of the Upper Clays here brought to light comprise only species with which we have been made familiar in the corresponding materials from Brabourne and Penshurst, and the whole assemblage is a characteristic one. At a depth of 1,268 feet a fine-grained brownish cement-stone containing minute specks of a paler colour was passed through, and this at once calls to mind the closely similar rock met with at Penshurst at a depth of 1,624 feet. The correspondence in lithological characters and the fact that *Astarte* cf. *mysis* was most numerous below the cement-stone in both localities makes it probable that the stone is at the same horizon in both places and may be used as an additional guide in correlating the Upper Clays in the two sections.

Having established the correspondence between the Upper Clays here with the equivalent part of the Kimmeridge Series in the other two borings examined, it is unnecessary to enter into the wider question of correlation. This has already been discussed in connection with the palæontology of the Brabourne section and will be further mentioned when we come to deal with the fossils obtained from Penshurst.

It was only possible to secure a very few fossils from the Virgula Beds at Pluckley, but these fortunately include several examples of *Exogyra virgula* from various depths. A specimen was collected from the core from a depth of 1,502 feet, and others were seen by one of us [G. W. L.] in the rock from depths of 1,529 feet, 1,548 feet, and 1,643 feet. This brings us nearly to the base of the boring, and it is therefore probable that no level below that corresponding with the base of the Virgula Beds at Dover and Brabourne was reached. It may be remembered that at those localities *Exogyra virgula* was much more sparingly present towards the base of the Virgula Beds than in the upper part, but that some similarly ornamented forerunners of small size were noted from the top beds of the Corallian Series. If, however, the Pluckley boring had penetrated even a short distance into those beds we might expect to find some sign of the millet-seed ironstone which formed such a marked feature at Dover and Brabourne, but no such rock was seen. We may therefore conclude that if the top of the Corallian Series was reached it could have been penetrated to no considerable depth; but in the absence of palæontological or other evidence it is equally probable that the boring did not even attain the base of the Virgula Beds. The scanty information here set forth regarding the palæontology of the Virgula Beds at Pluckley should of course be read in connection with the fuller account of the corresponding strata at Dover and Brabourne, in which also will be found some brief notes on the subject of correlation which need not be repeated here.

(1.) *Fossils from the Upper Kimmeridge Clays; depth,* 1,161 *feet to* 1,350 *feet.*

Depth in feet.	
1,162	Lingula ovalis *J. Sow.*
1,175	Pteria (Oxytoma) sp.
1,182	Orbiculoidea latissima (*J. Sow.*)
1,190	Pecten (Syncyclonema) demissus? *Phill.*
1,208, 1,210	„ (Camptonectes) morini? *de Lor.*
1,218	„ (Syncyclonema) demissus? *Phill.*
1,222, 1,240	Modiola autissiodorensis (*Cott.*)
1,250	„ „ Lingula ovalis *J. Sow.*
1,268	[Brown cement-stone; compare Penshurst boring at 1,624 feet]
1,272	Modiola autissiodorensis (*Cott.*); Protocardia morinica (*de Lor.*)
1,292	Perisphinctes sp.
1,312	Modiola autissiodorensis (*Cott.*); Aporrhais *cf.* piettei (*Buv.*); Astarte *cf.* mysis *d'Orb.*; Perisphinctes sp.; *Turbo*-like gasteropod. [Compare Penshurst boring at about 1,750 feet]
1,320	Astarte *cf.* mysis *d'Orb.*; Aporrhais *cf.* piettei (*Buv.*)
1,331	Lingula ovalis *J. Sow.*
1,338	? Lucina minuscula *Blake*
1,346	Modiola autissiodorensis (*Cott.*)

(2.) *Fossils from the Virgula Beds; depth,* 1,350 *feet to* 1,687 *feet.*

Depth in feet.	
1,350	Exogyra virgula (*Defr.*)
1,363	Protocardia morinica (*de Lor.*)
1,397	„ „
1,446	Exogyra virgula (*Defr.*) [numerous here]
1,452	Trigonia sp. [clavellate fragment]
1,459, 1,502	Exogyra virgula (*Defr.*)
1,516	Lingula sp.
1,529, 1,548, 1,643	Exogyra virgula seen at these depths [G. W. L.]
1,687	[Base of boring]

CHAPTER XII.

THE PENSHURST BORING.

Hastings Beds.

No evidence could be obtained to show the palæontological features of the uppermost 470 feet of Hastings Beds passed through in this boring, and fossils must have been very scarce in this part of the section, as indeed they were throughout the more sandy beds of the Hastings Series. Remains of ferns were met with at a depth of 474 feet, including fragments of fronds referable to *Leckenbya valdensis*. Fossiliferous beds below 500 feet yielded a number of species, noted below, including forms of *Unio* which, in the material available, are without exception crushed and unfitted for identification. *Estheria subquadrata* is elsewhere only known from the Hastings Beds.

As in the case of the other sections dealt with, the stratigraphical utility of the few remains obtained is very slight indeed. This is no doubt owing to the slow developmental progress commonly shown by fossil fresh-water forms, but also to the fact that the fauna of the Wealden Series of this country, in its relation to zonal succession, has been very imperfectly investigated.

Fossils from the Hastings Beds.

Depth in feet.	
474, 536	Plant remains, fragmentary
474	Leckenbya valdensis *Seward*
510	Cyrena parva (*J. de C. Sow.*)
510, 512, 530, 536	Unio spp.
510—512	Lamellibranch, gen. nov.? [*cf.* "Unio" gaulteri *J. de C. Sow.*]
510	Viviparus elongatus (*J. de C. Sow.*)
520	,, sp.
508	Cypridea dunkeri ? *Jones*
,,	,, valdensis (*J. de C. Sow.*)
520	Cyprids
514—536	Darwinula leguminella (*Forbes*)
533	Estheria subquadrata (*J. de C. Sow.*)
536	Lepidotus sp. [scale]

At a depth of 510 feet to 512 feet a *Unio*-band was passed through, where many valves were crowded together in a crushed and flattened condition. It is probable from the outlines of these imperfect remains that two species are present. Contrasted shapes such as are shown by *M. cordiformis* J. de C. Sow. and *M. valdensis* Mant. are suggested, but no definite determination of the specimens examined has been possible. The flattened valves of *Unio* which occur at 536 feet belong to an elongated form, but again the imperfection of the remains precludes identification.

Associated with *Unio* and *Cyrena* at about 510 feet in depth there occurs a somewhat problematical lamellibranch showing a peculiar sculpture of strong well-spaced concentric ribs. These ribs have a pronounced narrow upward bend about the middle. Examples of small size, not exceeding 5 mm. in height, are wholly

ribbed, but larger specimens show that this ornamentation did not persist beyond the neanic growth-stage and that with the acquirement of adult characters the valves are smooth. The adult shell is elongated. From the scanty material at hand, the correct orientation is uncertain. An example measuring about 25 mm. in length has somewhat the aspect of a *Thracia*. If the relation of parts be the same as in that genus, then the umbo is slightly posterior to the middle and is recurved. It seems possible, however, that this is J. de C. Sowerby's "*Unio*" *gaulteri*[1], which was described from the Hastings Beds near Tunbridge Wells, a species about which little is known. Small specimens of the shell from Penshurst have a very different shape from the large elongated one mentioned above. The same doubtful form has been found near Groombridge and there are specimens of it, preserved as external moulds, in the Museum of Practical Geology.

Purbeck Beds.

A general sketch of the distribution of the fossils observed to occur in the Purbeck rocks passed through in this boring, based upon observations made at the locality, has already been given in the previous part of this work. The list which here follows, with the depths at which the species occur, has reference only to a series of specimens brought away for examination and can give no complete picture of the real distribution.

As already noted, there is no break in the general palæontological characters in passing down from the Wealden Beds into the series here classified as Purbeckian. Fresh-water forms prevail without interruption throughout the strata above a depth of about 800 feet. It was at a depth between 820 feet and 830 feet that evidence for a marked incursion of brackish-water forms was clearest, for it was there that *Ostrea distorta*, *Perna*, and *Protocardia* were found. Just below the *Ostrea*-bed occurred a layer in which the large valves of a single species of *Protocardia* must have been crowded together in great abundance. As at Brabourne, we have therefore indications of an interruption in the purely fresh-water conditions which probably corresponds with the incursion of marine and brackish elements so well shown in the Middle Purbeck strata of Dorset.

Just as in the Wealden Series, so in the fresh-water Purbeck Beds, the relative permanence of character seen in the fossils renders the utilisation of these remains for purposes of correlation a difficult and doubtful matter. It is clear that too much importance must not be attached to the records of distribution of fresh-water species as set forth, for instance, in the table of Purbeck fossils from the Vale of Wardour given by Messrs. Andrews and Jukes-Browne[2]. In strata which were deposited under the peculiar conditions which must have prevailed at the

[1] In W. H. Fitton. 'Observations on some of the strata between the Chalk and the Oxford Oolite,' *Trans. Geol. Soc. Lond.*, ser. 2, vol. iv., 1836, p. 346, pl. xxi., fig. 16.

[2] W. R. Andrews and A. J. Jukes-Browne. 'The Purbeck Beds of the Vale of Wardour,' *Quart. Journ. Geol. Soc.*, vol. l., 1894, p. 68.

time, the character of the fauna at successive levels must have been influenced by inconstant local circumstances much more than by permanent evolutionary changes in the species themselves. It is indeed a feature of fresh-water faunas that developmental changes proceed slowly in them and that differentiation is much less rapid and less marked than under marine conditions. Were this not known to be the case, there would be great temptation to suppose that this fresh-water Purbeck fauna, distributed through such a thickness of strata as at Penshurst, lived under conditions of very rapid sedimentation.

Although not more than two species of *Cyrena* have been identified from these rocks at Penshurst, it is probable that others may also be represented among the fragments which are found crowded together on some of the bedding-planes. It is similarly probable that other forms of ostracods are present in addition to the three species named below, and the search for them has admittedly not been exhaustive. Yet the list of fossils as a whole is remarkable for the relative paucity of species compared with the profusion of individuals; and it is evident that the environment, perhaps that of muddy lagoons, did not favour the support of a very varied assemblage of organisms. This may account for the fact that some of the species selected to flourish under these conditions were able to do so without great stress of competition, and in this way the presence of innumerable individuals of a single species on many of the bedding-surfaces may be explained.

Fossils from the Purbeck Beds; depth, 552 *feet to* 1,114 *feet.*

Depth in feet.	
634	Equisetites sp.
585, 590, 808, 861	Plant remains [traces]
590, 700—764, 830, 834, 902	Cyrena media (*J. de C. Sow.*)
687, 725, 904	„ „ ?
725—787, 903	„ parva (*J. de C. Sow.*)
590, 740—785, 823, 847	„ sp.
628, 662, 689, 790	Cyrena ? [shells crowded and crushed]
904	Gervillia *cf.* arenaria *F. A. Roem.*
725	Modiola sp.
820	Ostrea distorta *J. de C. Sow.*
904	„ sp.
820, 830	Perna sp.
826, 827	Protocardia sp. nov. [a large form]
823	Unio sp. [a small form]
590, 774	Unio ?
629	Lamellibranchs [elongated, thin-shelled]
787	*Cf.* Melania rugosa *Dunk.*
590, 628, 787	Viviparus sp.
904	Gasteropods [minute, indet.]
687, 718—764, 835, 847	Cypridea punctata (*Forbes*)
835, 874, 903	Cypris purbeckensis *Forbes*
1,038, 1,110	Cypris ?
687, 718—785, 847, 874	Darwinula leguminella (*Forbes*)
634, 868, 1,038, 1,042	Ostracoda
1,038, 1,042, 1,110	Fish fragments

The fresh-water species mentioned in this list call for little remark. It may be noted that the small *Unio* found at a depth of 823 feet is not identical with *Unio sp.* (A) recorded from Brabourne, but is a more equilateral shell, with corroded umbones; the latter character is not shown by the Brabourne specimens. The preservation of the valves of both these species is a peculiar one. All that is seen of the original shell is an exceedingly thin layer of calcareous matter covered by the remains of the periostracum, still retaining a pronounced brown colour. These remains adhere closely to the surface of the undistorted cast, and it is difficult to understand how this state of preservation can have been brought about.

The valves of *Protocardia* found at a depth of 826 feet are of relatively large size, measuring as much as 43 mm. in length by 33 mm. in height. The umbo is sub-central and the figure of the valve is well elevated in front, with a broadly curved anterior border. The posterior area is demarcated by a narrow carina, and is ornamented by numerous and fine radial ribs. The remaining surface of the valve shows some traces of a discontinuous radial striation, weak and very delicate, and not assuming the nature of a pronounced sculpture: where the surface is well preserved this structure is least noticeable, but its presence becomes more evident when the surface layer is ill-preserved or removed. This species, which appears not to have been described, is not closely related to the smaller *Protocardia purbeckensis* which was found at Brabourne; *Protocardia deltoidea* (Maillard)[1] is more readily comparable on account of its larger size, but differs in the more elevated and more nearly triangular figure of the valve, and by the greater extent of the posterior ribbed area, the coarser radial ribs and the absence of carination. The Penshurst specimens show in some degree the sub-quadrate form usually associated with *Unicardium*, and are much less nearly triangular than a carinated *Protocardia* of large size which is known to occur in the Middle Purbeck rocks of Swanage. The smaller-sized valve of a *Protocardia* found at Brabourne, which also represents a new species, cannot be brought into comparison and is well separated by its peculiar shape and concentric ornamentation.

At a depth of 904 feet the presence of *Ostrea* and *Gervillia* points to a still earlier influence of estuarine conditions. The *Ostrea* is an irregular and dwarfed form occurring in poor preservation with the valves crowded together to form thin bands. The *Gervillia* is also of small size, and so far as its characters can be ascertained it recalls the figures of *G. arenaria* given by Roemer and by Maillard[2]. In the rounded frontal profile and the strong convex fold of the valve it resembles *G. obtusa* F. A. Roem.[3],

[1] G. Maillard. 'Invertébrés du Purbeckien du Jura,' *Mém. Soc. Pal. Suisse*, vol. xi., 1884, p. 99, pl. iii., fig. 17.

[2] F. A. Roemer. 'Die Versteinerungen des norddeutschen Oolithen-Gebirges. Nachtrag,' 1839, pl. xviii., fig. 33. G. Maillard, *op. cit.*, pl. iii., figs. 35, 36. See also figures of small forms ascribed to *G. arenaria* by C. Struckmann, 'Die Wealden-Bildungen der Umgegend von Hannover,' 1880, pl. ii., figs. 19, 20.

[3] F. A. Roemer, *op. cit.*, pl. xviii., fig. 35. G. Maillard, *op. cit.*, pl. iii., figs. 37, 38.

but in that species the hinge-line seems to be relatively shorter. A final determination of these little specimens is not possible with the material at hand.

Portland Beds.

The fossils from the Portland Beds in this boring, particularly those from the sandstones, are very poorly preserved. The sharp lithological change between the uppermost Portland and the lowest Purbeck Beds was accompanied by an equally abrupt transition from a purely marine molluscan assemblage to a fauna in which ostracods furnished the principal remains. As at Brabourne, *Pecten lamellosus* was only met with in the highest Portland strata, and there abundantly, so it may at least be inferred that it was less commonly present in the lower part of the series. No undoubted remains of the characteristic *Trigoniae* of the division *Gibbosae* were found here, but this absence can only be ascribed to the accidents of collection.

Just as in the other two borings in which the Portland rocks were penetrated, the beds which we ascribe to this formation at Penshurst correspond only with the Portland Stone Series of Dorset (including the Cherty Beds), that is to say the Upper Portland Beds of Mr. H. B. Woodward's classification. It has been shown, and will be further emphasised below, that the term Upper Kimmeridge Clay may best be applied in Kent so as to comprise those upper beds which are equivalent to the Portland Sands of Dorset. The reasons for not placing the base of the Portland Series at a lower level in this district have already been touched upon in the discussion on the palæontology of the Kimmeridge Clay of Brabourne, and will be further dealt with below. Here, just as in Dorset, the fauna of the beds which immediately underlie the Portland Stone Series is more closely related to that of the Upper Kimmeridge Clay than to that of the Portland Stone.

In Kent the palæontological change is a well marked one, so far as it has been revealed by the borings. The common and characteristic *Modiola autissiodorensis* has an abruptly defined upward limit which, just as in Dorset, may be taken to mark the division-line between the Portland Sands and the Portland Stone Series. Above this line in these Kentish borings "*Holcostephani*" resembling *H. pallasianus* are no longer seen, but the remains of large forms comparable with *H. bononiensis* are found. *Lingula ovalis* is not met with, and the occurrence of large valves of *Perna*, which must have been present in great numbers in the basal beds, introduces a feature not noted in the underlying strata or in the Portland Sands of Dorset. It is true that Blake recorded two species of *Perna* from the Portland Sand of Swindon, but the associated fossils include some gasteropods and other forms, such as *Astarte saemanni*, which indicate a shallower water facies than that exhibited by the corresponding clays at Penshurst. But the ubiquitous *Modiola autissiodorensis* is present in the Sand at Swindon, just as in Dorset, and the fact that this fossil was not found in the shaly beds with *Perna* at Penshurst perhaps gives sufficient justification for classing these beds as the basal part of

the Portland Series rather than with the top of the Upper Kimmeridge Clay.

Correspondingly, in comparison with the "Portlandian" rocks of the Boulonnais, we may suppose the division between the equivalent of the Portland Sands and of the Cherty Beds of the Portland Stone Series to occur in the upper part of Pellat's "Middle Portlandian," in his division O_2 or perhaps at its base. *Modiola autissiodorensis* appears not to have been found above the clays of Pellat's O_1. According to Pellat and Blake, the "Upper Portlandian" of the Boulogne district is only equivalent to the Cherty Beds of our Portland Series, and does not include the Portland Stone proper[1]. The evidence obtained from these borings does not permit us to state with any exactitude how much of the series in Kent corresponds with this incomplete representative of our true Portlandian in the Boulonnais.

Fossils from the Portland Beds; depth, 1,114 *feet to* 1,245 *feet.*

Depth in feet.	
1,114, 1,120	Serpula sp.
1,229, 1,236, 1,237	Rhynchonella sp.
1,237	Exogyra bruntrutana *Thurm.*
1,242	Lucina ?
1,114	Modiola boloniensis (*de Lor.*)
1,226	Pecten (Syncyclonema) demissus *Phill.* [? = P. solidus *Roem.*]
1,114, 1,115	Pecten (Camptonectes) lamellosus *J. Sow.*
1,115, 1,237	Perna bouchardi ? *Oppel*
1,237	„ sp.
1,120	Pleuromya ?
1,115, 1,118, 1,120	Trigonia sp. [clavellate]
[1,165], 1235	"Holcostephanus" *cf.* bononiensis (*de Lor.*) [Blake's interpretation]
1,218	"Holcostephanus" giganteus ? (*J. Sow.*)
1,118	„ sp.
1,228	Lepidotus sp. [tooth]

Kimmeridge Clay.

Some reference has already been made to the Kimmeridge Beds of Penshurst in the discussion which precedes the list of fossils from the corresponding rocks of Brabourne. It was shown that the series is incomplete in its upper extent at Brabourne, but that further west at Pluckley, and again at Penshurst, there is an unbroken transition between the Kimmeridge and Portland Beds. We have concluded, from the palæontological comparison, that the uppermost 250 feet or so of the Upper Clays of Penshurst are unrepresented at Brabourne, and that, judging from the actual difference in thickness between the Upper Clays present at Brabourne and the strata at Penshurst with which they may be correlated, the missing beds would be reduced to a thickness of about 40 feet at Brabourne.

The uppermost 100 feet of the series at Penshurst contain a fauna which links these beds more closely with the Kimmeridge

[1] J. F. Blake. 'On the Portland Rocks of England,' *Quart. Journ. Geol. Soc.*, vol. xxxvi., 1880, p. 566.

Clay than with the Portland Beds. *Modiola autissiodorensis* occurs at the very top, but was not found above this. A relative abundance of the remains of "*Holcostephani*" also characterises these highest beds of the series. In the succeeding 100 feet or so of strata, passing downwards, the abundant occurrence of *Cyprina implicata* and a distinctive type of *Grammatodon* was the most notable palæontological feature. It was below a depth of 1,500 feet, however, that the typical association of forms with which we were made familiar in the Upper Clays of Brabourne was first met with. Here occur *Orbiculoidea latissima, Astarte* cf. *mysis, Cyprina sp.* (A), *Modiola autissiodorensis, Protocardia morinica, Aporrhais* cf. *piettei,* and "*Holcostephanus*" *pallasianus?*. The lowest 200 feet of clays penetrated by this boring yielded some Upper Kimmeridge forms, such as *Lucina minuscula,* which were not found in the Brabourne cores, but *Modiola autissiodorensis* occurred right down to the base, and it is clear that the Virgula Beds were not reached in this boring.

We may consider for a moment the evidence which leads us to conclude with such certainty that the Upper Clays of the more easterly sections are represented here by a series having the remarkable thickness of 622 feet, and we find it to be sufficiently decisive. We have seen that at Brabourne and Pluckley the downward distribution of *Modiola autissiodorensis* extended to the top of the Virgula Beds, but no lower, and there is no reason to suspect a misleading departure in the vertical distribution of this form at Penshurst. Then the associated fossils comprise no species which is distinctive for the Virgula Beds. *Exogyra virgula* itself was not seen, although this is known to be abundant in the upper part of the Virgula Beds, and was duly represented in the cores when that part of the series was entered in the more easterly borings as well as in the deep borings near Hastings. Its absence here is therefore a striking circumstance, and is a piece of negative evidence to which due weight must be attached. There is the absence also of *Gervillia kimmeridgensis, Astarte ingenua,* and other species of the Virgula Beds which were well represented in the Brabourne cores, and a study of the whole assemblage met with in the Virgula Beds and a comparison with the fossils from the lowest cores at Penshurst can only confirm us in the conclusion that the Virgula Beds were not reached here.

It is doubtful, indeed, whether the base of the Upper Clays was attained; there is certainly no decisive evidence that this is the case. The lower beds of these clays at Penshurst are more finely laminated, and of darker colour than the corresponding strata at Brabourne, and this fact may be thought to suggest that the distribution of some of the species was influenced by the slight difference of facies, owing to deeper water conditions at Penshurst. This might perhaps be considered to account for the absence at Brabourne of *Lucina minuscula* and a small and delicate *Astarte,* which occur at Penshurst. But we think it more probable that these perishable forms, though originally present, have not left recognisable traces in the coarser sediments of the more easterly locality. This explanation would account for the apparent

absence at Brabourne of the little pyritized radial plates of *Saccocoma*, which occurred at Penshurst. The distribution of this pelagic genus would be likely to be quite uninfluenced by any local change of facies; certainly by one so slight as in the case we are discussing. There is little probability, on the other hand, that such a conspicuous species as *Lucina* cf. *lirata*, which was very noticeable in the lower part of the Upper Clays at Brabourne, would escape detection in the Penshurst core, had any beds containing it in considerable numbers been passed through; and the fact that this form was not seen there may perhaps be taken to lend some likelihood to the assumption that the lowest beds of the Upper Clays were not completely penetrated. Having regard, however, to the somewhat precarious character of this single piece of evidence, too much weight must not be attached to it.

The correlation of the Upper Clays has already been discussed in connection with the palæontology of the Brabourne section; but since the series is complete in its upward extent at Penshurst and the evidence of the fossils from the topmost beds is important, a few words may be added here. It is well known that in Dorset the Portland Sands merge downwards without a definite lithological break into the true Kimmeridge Clay, and this fact has led to the discrepancy between the lower boundary selected for the Sands by Fitton and afterwards by the Geological Survey, and that chosen by the late Prof. Blake. Regarded palæontologically, it must be admitted that the Portland Sands are much less definitely separated from the Upper Kimmeridge Clay than from the Portland Stone Series above, which was classified by Mr. H. B. Woodward as Upper Portland Beds. In the Kentish borings with which we are dealing no characters are revealed towards the top of the Kimmeridge Series which could justify the use of the term Portland Sands, but the whole of these Upper Clays form part of a stratigraphically indivisible unit. We see, however, that the upward range of *Modiola autissiodorensis* ceases at the top of the Upper Clays, and in Dorset the latest appearance of this fossil is in the top part of the Portland Sands, where it occurs abundantly. This fact was noted by Blake at St. Alban's Head, and has been recently observed in a boring through the Portland Series near Upway, where Mr. J. Pringle found the topmost marly beds of the Portland Sands to contain abundant fragments of this fossil. Specimens are now in the collection of the Geological Survey. The manner in which the palæontological characters of the overlying Portland Stone Series differ from those of the Portland Sands of Dorset and the Upper Clays of the Kimmeridge Series in the Kentish borings has already been pointed out on a previous page.

We may therefore conclude that the top of the Upper Clays in Kent corresponds at least very closely, and perhaps absolutely, with the junction between the Portland Sands and the overlying Cherty Beds of Dorset. It has become increasingly evident that the Portland Sands may be considered to illustrate a facies connected with shallowing in the upper part of the Upper Kimmeridge Clay of some districts, and the extension of our knowledge

by means of the borings in Kent has thus given material support to the view of Blake, who desired to draw the base of the Portland Beds above the Portland Sands[1]. As already mentioned, Blake's suggestion to apply the name "Bolonian" to the strata in the South of England between the top of the Virgula Beds and the top of the Portland Sands does not commend itself, because the lower 500 feet or so of these beds in Dorset must be regarded as forming a very substantial part of the true Kimmeridge Clay of the type-district.

These considerations must accentuate the regret, repeatedly expressed by writers on this side of the Channel, that the French geologists, in applying the name Portlandian so comprehensively to the rocks of the Boulogne neighbourhood, insufficiently realised the actual relations of the Kimmeridge and Portland Beds of the type-area in England from which these names are taken. It is evident that the Upper Clays of the Kimmeridge Series revealed in the borings in Kent and Sussex correspond broadly with a considerable part of the "Lower Portlandian" and with the "Middle Portlandian" of Pellat's classification, excluding only some of the highest beds (in O_2) in which *Modiola autissiodorensis* does not appear to have been found. Even when the Portland Sands of Dorset were classified without question as a part of the Portland Series, it is difficult to understand why the term Portlandian should have been made to include those beds in the Boulonnais which correspond with the hundreds of feet of Kimmeridge Clay which overlie the Virgula Beds and underlie the Portland Sands. The widespread use of the name Portlandian in this too extended sense on the Continent has undoubtedly helped to obscure the correlation in an unnecessary degree to those who do not possess a first-hand acquaintance with the actual strata in the respective areas. If the term Upper Kimmeridge Beds cannot fittingly be used across the water, then the acceptance of Blake's name "Bolonian," in place of the misapplied terms "Lower" and "Middle Portlandian," is much to be desired. It must be remarked that there is risk of further confusion arising from the use of such a terminology as that adopted for the beds in question by Professor Pavlow in his well-known correlation-table published in 1896[2]. In that table the term Kimmeridgian is applied to the Virgula Beds alone, while the remaining Upper Kimmeridge Clays and the overlying Portland Beds, including even the Portland Stone Series, are termed "Portlandian or Bononian." This suggestion to extend the use of the term Bononian (or Bolonian) so as to include the Portland Stone Series appears to be quite as lacking in justification as the application of the term Portlandian to the series which is situated between the Portland Sands and the Virgula Beds.

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[1] J. F. Blake. 'On the Correlation of the Upper Jurassic Rocks of England with those of the Continent. Part 1. The Paris Basin,' *Quart. Journ. Geol. Soc.*, vol. xxxvii., 1881, p. 567.

[2] A. P. Pavlow. 'On the Classification of the strata between the Kimmeridgian and Aptian,' *Quart. Journ. Geol. Soc.*, vol. lii., 1896, p. 542 (see table facing p. 548).

Fossils from the Upper Kimmeridge Clays; depth, 1,245 *feet to* 1,867 *feet.*

(a). Depth, 1,245 feet—1,350 feet.

Depth in feet.	
1,267—1,317	Lingula ovalis *J. Sow.*
1,270, 1,277	Astarte sp.
1,320, 1,321	Cyprina implicata *de Lor.*
1,300	Lima (Plagiostoma) sp.
1,247—1,270	Modiola autissiodorensis (*Cott.*)
1,270, 1,290	Ostrea sp.
1,300	Pecten (Syncyclonema) demissus? *Phill.*
1,301	„ (Camptonectes) morini? *de Lor.*
„	Pholadomya sp.
1,250	Pinna sp.
1,350	Trigonia pellati? *Mun.-Chalm.*
1,251	"Holcostephanus" *cf.* giganteus (*d'Orb.*) [non *Sow.*]
1,301, 1,320	„ pallasianus? (*d'Orb.*)
1,264	„ *cf.* pallasianus (*d'Orb.*)
1,247, 1,295, 1,300	„ panderi? (*d'Orb.*) [? *Eichwald*]
1,255	„ trifurcatus evolutus (*Quenst.*)
1,257, 1,264	„ sp.
1,301	Perisphinctes capillaceus? (*Font.*)
„	„ effrenatus? (*Font.*)
1,300	„ sp.

The topmost bed yielded *Modiola autissiodorensis*, the highest appearance of this fossil in the boring. The principal characters of the species have been pointed out in the remarks on the list of fossils from the Upper Clays of Brabourne, but the materials from that locality did not give the opportunity to compare specimens from the highest Kimmeridge Beds with those which occur at lower levels. It is noticeable that the examples from the top beds at Penhurst are of smaller size than those found lower down in the series, and are relatively less elongated and also show a less degree of postero-ventral expansion. In these points they agree with the specimens from the top part of the Portland Sands in Dorset, and it thus becomes highly probable that they illustrate zonal mutational characters (in Waagen's sense). Unfortunately the shells of this species are delicate and are liable to distortion by crushing, but the differences of shape here noted suggest that if a sufficient number of well preserved individuals from different horizons in the Upper Clays could be brought together, they might repay a special study and lead to the recognition of further mutational characteristics in the group at other zonal positions in which it occurs. If the features which characterise the genus *Modiolaria* Lovén, which is considered by some writers to be worthy merely of sub-generic rank under *Modiola*, could be shown to be homogenetic, then this species should be placed in that genus.

Judging by the number of specimens found in the cores, a lamellibranch which we have identified as *Cyprina implicata* must have occurred numerously in the strata between 1,320 feet and 1,400 feet in depth. This species is found in the "Middle Portlandian" of the Boulonnais, so that it occurs at Penshurst just where one would expect to meet with it.

Some of the specimens of ammonites ascribed to "*Holcostephanus*" in the foregoing list are the remains of individuals of

larger diameter than that of the boring. Their peripheral parts have in some cases been entirely cut off by the circumference of the boring, but in other examples the ammonite is situated so excentrically in relation to the axis of the core that a portion of the periphery of the last whorl is shown. In most cases some degree of doubt must attach to the attempted identifications, having regard to the state of the specimens, but the general character of the fauna is made sufficiently clear and it is well established that "*Holcostephani*" are the predominant forms in these highest beds. The remarks on the ammonite-fauna of the Upper Kimmeridge Beds of Brabourne, which will be found to follow the list of fossils from that section, may also be read in connection with this list of the fossils from Penshurst.

(b). Depth, 1,350 feet—1,460 feet.

Depth in feet.	
1,458	Lingula sp.
1,388, 1,407	Rhynchonella sp.
1,360—1,388	Cyprina implicata *de Loriol*
1,360—1,458	Grammatodon *cf.* rhomboidalis (*Cont.*)
1,353	Pecten sp. [finely ribbed]
„	"Holcostephanus" pallasianus? (*d'Orb.*)
1,438	„ *cf.* pallasianus (*d'Orb.*)
1,357, 1365	„ spp.
1,445	Belemnites sp.

In the notes relating to the palæontology of the Kimmeridge Clay at Brabourne reference has already been made to a species of *Grammatodon*, absent at Brabourne, which is present at Penshurst between the depths of 1,360 feet and 1,460 feet—the *Grammatodon* cf. *rhomboidalis* of the above list. This is so well represented in the boring-core as to show its great abundance. It was just below 1,360 feet in depth that the species was most numerously found, but specimens were met with at intervals throughout the succeeding 100 feet of strata. This well characterised fossil appears to belong to an undescribed species. It agrees very closely in shape with *Grammatodon rhomboidalis* (Contejean), which occurs at a lower horizon, with *Exogyra virgula*, in the South of France[1]. This has distinctive points which are well shared by the specimens from Penshurst, particularly the manner in which the frontal margin slopes away rapidly when traced down from the anterior extremity of the cardinal line. This feature is even more marked in our specimens, but they are definitely separable from *G. rhomboidalis* on the ground that they lack radial ribs at the anterior end and on the posterior area. Some of the specimens have had much of the shell substance removed, and are preserved as beautiful casts, but others in which the shell is present do not show any ribs, traces of which we might expect to find even on the casts, had they been present. The minute concentric linear banding which marks the surface of the shell has the nature of delicate growth-lines, and although it is more regular in some specimens than in others, in no case can it be described

[1] C. Contejean. 'Étude de l'étage Kimméridien dans les environs de Montbéliard,' 1859, p. 287, pl. xvii., figs. 8, 9.

as definite sculpture. It may be noted that these specimens are less closely comparable with the shell from the Virgulien, near Boulogne, which de Loriol has ascribed to *G. rhomboidalis* (as *Arca*)[1] than with the form originally figured by Contejean.

A few ill-preserved remains of ammonites from the upper beds, too imperfect for identification, show characters which recall species of the Tenuilobatus Zone. Thus, a fragment of a small, fairly involute and finely-ribbed specimen from a depth of 1,365 feet has been compared by Mr. Buckman with "*Holcostephanus*" *moeschi* (Oppel), a species which was described from the Tenuilobatus Beds of Aargau, and is said to occur in the uppermost Sequanian of the Boulonnais. There is such a zonal discrepancy here that it might be misleading to enter in the above list any reference to Oppel's species, to which our specimen may in reality not bear near relationship. It may be remarked once more that our knowledge of the Kimmeridgian ammonites of this country is still very scanty; hence in many cases there is bound to be difficulty in recognising the near relationships of crushed or fragmentary specimens.

(c). Depth, 1,460 feet—1,660 feet.

Depth in feet.	
1,554—1,659	Lingula ovalis *J. Sow.*
1,541—1,653	Orbiculoidea latissima (*J. Sow.*)
1,657	Astarte hartwellensis *J. de C. Sow.*
1,584	„ *cf.* mysis *d'Orb.*
1,565, 1,571	„ sp. (C)
1,634, 1,652	Cyprina sp. (A)
1,514	Lucina?
1,565—1,635	Modiola autissiodorensis (*Cott.*)
1,461, 1,538	Ostrea sp.
1,576	Pecten (Camptonectes) morini? *de Lor.*
1,557, 1,592	Pleuromya?
1,587—1,652	Protocardia morinica (*de Lor.*)
1,591	Pteria (Oxytoma) sp.
1,554—1,653	Aporrhais *cf.* piettei (*Buvign.*)
1,461, 1471	"Holcostephanus" pallasianus? (*d'Orb.*)
1,465, 1,471, 1,542	„ spp.
1,575	Scalpellum? sp. nov.
1,627, 1,653	Fish remains [scales and spines]

It is in this part of the section that we recognise the greatest resemblance between the fauna and that found in the Upper Clays of Brabourne. Very few fossils were obtained from the uppermost 80 feet in this portion of the boring-core, but it was in the topmost beds that most of the remains of "*Holcostephani*" were found. Again, these include fragments which Mr. Buckman has felt inclined to compare with species from the Tenuilobatus Zone. Such occur at 1,465 feet and 1,471 feet from the surface, but their state of preservation is so imperfect that no attempt can be made to indicate their true specific relationships.

[1] P. de Loriol and E. Pellat. 'Monographie paléont. et géol. des étages supérieurs de la Formation Jurassique des Environs de Boulogne-sur-Mer,' *Mém. Soc. Phys. et d'Hist. Nat. de Genève*, vol. xxiv., part 1, 1875, pl. xviii., figs. 2, 3.

In this part of the series the specimens of *Modiola autissiodorensis* belong to the large and posteriorly elongated form which was obtained at Brabourne. *Orbiculoidea latissima*, *Astarte* cf. *mysis*, the large *Modiola autissiodorensis*, *Protocardia morinica* and *Aporrhais* cf. *piettei* are some of the most characteristic fossils of the Upper Clays of Brabourne, and it is their appearance here below a depth of 1,540 feet, and their absence above, which leads us to say that the Upper Clays at Brabourne cannot be regarded as including strata equivalent to any of the beds above a depth of about 1,500 feet at Penshurst. The above species are those which were found only a short distance below the top of the Upper Clays at Brabourne. Unfortunately nothing was obtained at Penshurst from the cores between 1,460 feet and 1,540 feet in depth that can be of service in a comparison with the fauna at Brabourne. Hence it is difficult to give an exact line of correspondence with the top of the Kimmeridge Clay of Brabourne, but there is every probability that some depth close to 1,500 feet is a correct estimate, and we may take this figure as sufficiently near for the purpose of tabulation.

The small, well-ribbed specimens of *Astarte* which occur in the Kimmeridge Clay of Penshurst have proved as perplexing to identify as the similar shells from the Upper Clays at Brabourne. It is probable that amongst these strongly ornamented forms at least three species are represented. One of these, named *Astarte sp.* (C) in the list of fossils was found at a depth of 1,565 feet, and is characterised by elongated form and ribbing which is relatively delicate in comparison with that of the two other forms about to be mentioned. A specimen measuring 10 mm. in length is 6 mm. high, measured from the umbo, and about 14 ribs may be counted on its surface. The long and gentle slope of the upper margin posteriorly to the umbo, the straight outline formed by the lower margin of the valve, and the posterior truncation, alone suffice to distinguish this form from the others which occur here. One or two specimens from the Brabourne cores which show resemblance in their relatively elongated outline are readily separable by the coarser character of their ribbing. A second species, seen first at 1,584 feet, but most abundantly represented in the cores from a depth of about 1,750 feet, has a more trigonal form and more rounded outlines, greater relative height, and coarser ribbing. This is identical with specimens from Brabourne which we have named *Astarte* cf. *mysis*. The third species is mentioned below.

(d). Depth, 1,660 feet—1,867 feet.

Depth in feet.	
1,794, 1,796, 1,806	Saccocoma sp. [radials]
1,665	Lingula ovalis *J. Sow.*
1,796	Orbiculoidea latissima (*J. Sow.*)
1,771	Astarte hartwellensis *J. de C. Sow.*
1,751—1,785	„ *cf.* mysis *d'Orb.*
1,768—1,862	„ sp. (D)
1,785, 1,794	„ sp. (E)
1,796, 1,817	„ sp.
1,700—1,787	Cyprina sp.
1,806, 1,862	Grammatodon sp.

Depth in feet.	
1,766—1,862	Lucina minuscula *Blake*
1,661—1,867	Modiola autissiodorensis (*Cott.*)
1,767	Pleuromya *cf.* recurva (*Phill.*)
1,771—1,862	Protocardia morinica (*de Lor.*)
1,867	Pteria (Oxytoma) inequivalvis ? (*J. Sow.*)
1,767	Pleurotomaria ?
1,864	Perisphinctes guentheri (*Oppel*)
1,806	„ „ ?
1,807	„ sp. [*cf.* lusitanicus *Siem.* and eudichotomus *Zitt.*]
1,780—1,862	Fish remains [very fragmentary ; teeth and scales]

In addition to *Astarte* cf. *mysis*, which was numerous at a depth of about 1,750 feet, there occurs, at a few feet below this, another form, quite distinct from the two last mentioned. This we have not succeeded in identifying, and it is referred to as species (D) in the list. The shell has a more nearly sub-quadrate outline than *A.* cf. *mysis*, and is more coarsely ribbed. Of the published figures with which it can be brought into comparison, it agrees most nearly with the shell from the " Middle Portlandian " of the Boulonnais, ascribed by de Loriol to Roemer's *A. scalaria*[1], and the resemblance is very close. It is probable that the shell figured by de Loriol is not identical with Roemer's species, and the Penshurst specimens cannot be brought into close comparison with the figure given by Roemer or that of an Upper Corallian shell ascribed by Dollfus to the same species.

Other small specimens which may be provisionally referred to *Astarte* occur below a depth of 1,780 feet. These average less than 5 mm. in length, and the flatness and compression of their valves is no doubt partly due to the mode of preservation. The surface is ornamented by exceedingly delicate linear concentric ribs separated by narrow striæ. The extreme delicacy of this sculpture readily distinguishes these specimens from those at Brabourne which we have referred to *A. ingenua* de Lor., and since these little shells have not yet been identified, and probably belong to an undescribed form, we may refer to them as *Astarte sp.* (E).

Below a depth of 1,765 feet many individuals of small sized and delicate lamellibranch-shells were found, and one of these species must be recognised as *Lucina minuscula* Blake. This was found at intervals almost down to the base of the boring. Another form not differing widely in its external characters, but more elongated and narrowed posteriorly and rather less equilateral than the last, may be provisionally ascribed to some species of *Cyprina*. The largest valves found only measure 11 mm. or 12 mm. in length and about 9 mm. in height at the umbo.

It remains to mention some little organisms which for a time seemed to be of a problematical nature. Eventually it was considered that these might possibly be the relics of some free-swimming crinoid, and the specimens were accordingly submitted

[1] P. de Loriol and E. Pellat. 'Monographie paléont. et géol. des étages supérieurs de la Formation Jurassique des Environs de Boulogne-sur-mer,' *Mém. Soc. Phys. et d'Hist. Nat. de Genève*, vol. xxiv., part 1, 1875, pl. xv., figs. 5, 6.

to Dr. F. A. Bather, who has recognised them to be the radial plates of *Saccocoma*, and has furnished us with a short preliminary account of them[1]. These minute, thin, scutiform, plates were only found at depths between 1,794 feet and 1,807 feet. They are all pyritized, and are the only organisms observed to be fossilised in this manner in this part of the clays. They occurred abundantly on several layers between these depths, but were not found in any other of the borings, nor could we discover anything resembling them in the public collections of Kimmeridge fossils. It curiously happened, however, that one of us [G. W. L.], shortly after finding the form at Penshurst, chanced upon further examples in a large transported fragment of shale embedded in the Ferruginous Sands of the Lower Greensand at Little Stairs Point, near Sandown, in the Isle of Wight[2]. The new occurrence was doubly interesting in proving (1) that the Kimmeridge Clay was exposed to erosion at some neighbouring place in Aptian times; and (2) that the little fossil is likely to have been widely distributed. Attention having now been drawn to it, we may expect that it will be discovered in the Kimmeridge Clay at other localities.

[1] 'Summary of Progress' for 1910 (*Mem. Geol. Surv.*), 1911, Appendix II, p. 78.

[2] This occurrence was mentioned in 'Summary of Progress' for 1900 (*Mem. Geol. Surv.*), 1901, pp. 118, 119.

CHAPTER XIII.

PALÆONTOLOGICAL SUMMARY.

The correlation of the marine Jurassic strata passed through in the four sections is represented diagrammatically in Plate V. In the following notes the chief palæontological evidence obtained from the formations situated between the Trias and the Gault Clay is reviewed in ascending stratigraphical order.

Lias.

A study of the fossils from the Lias passed through at Dover and Brabourne shows that this formation is unequally represented at these two localities. At Dover the grey clay forming the lowest 4 feet of the Lias, which rests directly upon Coal Measures, has yielded *Liparoceras maculatum* (Y. and B.), giving decisive evidence for the Capricornus Zone. At Brabourne about 60 feet must be ascribed to this zone, and this inequality in the two sections may be accounted for partly by the westerly expansion in the thickness of the strata, but also by the probable absence of any but the upper part of the zone at Dover. Species of *Astarte* and *Nuculana* which occur numerously at Brabourne below a depth of 1,800 feet, in the lower beds of the zone, were not seen in the Lias at Dover. Species of *Liparoceras*, including *L. maculatum*, were found at Brabourne down to a depth approaching 1,820 feet, and the presence of specimens referred with some doubt to *L. arcigerens* (Phill.) suggests, according to Mr. Buckman, that a lower level in the Capricornus Zone is here reached than that which is characterised by *L. maculatum*.

A few forms occur at Brabourne which indicate the presence of the underlying Jamesoni Zone. Such are *?Polymorphites trivialis* (Simps.), *Rhynchonella* cf. *rostellata* (Quenst.), and *R. rimosa* (von Buch). The last-named was found below a depth of 1,820 feet in the ferruginous beds underlying the grey clay. While the basal part of the grey clay and a portion of the ferruginous beds can be ascribed to the Jamesoni Zone, the palæontological evidence leaves it uncertain whether the Raricostatus Beds (the upper part of the Oxynotus Zone) are represented in the lowest strata as we approach the depth of 1,840 feet at Brabourne. The occurrence here of *Lima antiquata* J. Sow. may perhaps speak for their presence.

In the Middle Lias at Dover only one fossiliferous horizon could be detected—a belemnite-bed yielding *Belemnites breviformis* Voltz, and probably other forms. *B. breviformis* is elsewhere found in the Spinatus Zone. The evidence of ammonites was wanting both here and at Brabourne, but at the latter locality, where the Middle Lias was much more thickly developed than at Dover, the beds ascribed to this subdivision yielded in their upper part *Rhynchonella capitulata* Tate, *R. tetrahedra* (J. Sow.) and *Pecten aequivalis* J. Sow., amongst other forms. *Rhynchonella capitulata* is elsewhere known as a characteristic fossil of the

Spinatus Zone. The underlying Margaritatus Zone is also doubtless represented, and amongst the numerous lamellibranchs found in this part of the series there occurs a species of *Nuculana* which is elsewhere only known to occur in beds of that age.

The uppermost 5 feet of Lias Clay at Dover have yielded *Dactylioceras delicatum* (Simps.), *D. annulatum?* (J. Sow.) and *Orbiculoidea reflexa* (J. de C. Sow.) amongst other species, and the ammonites show that nothing higher than the Serpentinus Zone is represented at this locality. This top bed is unconformably overlain by a sand belong to the Oolitic Series. At Brabourne we have obtained no palæontological evidence for the presence of the Serpentinus Zone, and it is certain that it can be only very thinly developed here. If it is not represented by any perceptible thickness of rock this is probably due to temporarily arrested sedimentation, and there is no sign of actual unconformity. The overlying Communis Zone is attested by species of *Dactylioceras*, *Hildoceras* and *Peronoceras*, which Mr. Buckman ascribes to the Bifrons fauna. He considers that the occurrence of a *Grammoceras* resembling *G. striatulum* (J. de C. Sow.), to be assigned to the Striatulus Beds, indicates that above the beds of the Communis Zone the Jurensis Zone is also represented at this locality. There are no indications for strata of still later Toarcian age, and the series is unconformably overlain by a limestone belonging to the Oolitic Series.

We thus see that the Lias, while imperfectly represented at Brabourne, is reduced at Dover to a band of Middle Lias with merely a thin fringe of Upper and Lower Lias.

Strata between the Kellaways Rock and the Lias.

These Oolitic beds were passed through in the Dover and Brabourne sections. At neither locality has palæontological material been obtained from the lowest part of the series, so that there are no certain means of measuring the extent of the unconformity between Toarcian and Oolitic beds at the two places. The fossils obtained from the Sandy Series at Dover at about 40 feet from the base—that is to say, at above a depth of 1,083 feet—show that the sinking was still in the Great Oolite at that level. *Terebratula bathonica* (S. S. Buckm.) and species of *Rynchonella* of Great Oolite facies provide evidence which is well supported by a sufficiently characteristic assemblage of lamellibranchs. The limestones above this have also furnished several typical species of the Great Oolite. Fossils were relatively scarce throughout the whole of the series, and no remains of cephalopods were found. The strata assigned to the Forest Marble at Dover yielded very little palæontological evidence for a correlation, and only one species which is common in this part of the sequence elsewhere was met with, *Astarte fimbriata* Lycett. The Cornbrash at Dover is probably much more fossiliferous than would appear from the list given on a preceding page, and this apparent paucity of species is to be accounted for by unfavourable conditions for collecting. *Pseudomonotis echinatus* (J. Sow.) and *Pholadomya*

phillipsi Lyc. were the principal fossils found here, but at Tilmanstone Colliery, outside the immediate area with which we are dealing[1], the Cornbrash has shown close lithological agreement with its development at Dover and has yielded several other typical species.

At Brabourne the boring cores from the lowest 70 feet or so of the Oolites contained only a few inconclusive remains of lamellibranchs, so that as far as the fossils are concerned there is nothing to show that the Inferior Oolite is represented here. Above a depth of 1,633 feet from the surface ample evidence for a Great Oolite age is furnished by the remains, principally of lamellibranchs, which were obtained. These include *Corbula buckmani* Lyc., *Nuculana lachryma* (J. de C. Sow.), *Pecten retiferus* Morr. and Lyc., *Pseudomonotis echinatus* (J. Sow.), and species of *Placunopsis*, as well as other forms. Palæontological evidence again fails us as an aid in the attempt to allocate with precision certain overlying beds to the Forest Marble and Cornbrash, but the indications are in favour of placing the base of the Kellaways Rock at a depth of a few feet below 1,500 feet. It is probable that the equivalent of the Cornbrash, as seen at Dover and Tilmanstone, is very thinly developed at Brabourne.

Kellaways Rock.

In the strata assignable to this formation, with which we are concerned only at Dover and Brabourne, the principal fossils found were *Gryphaea bilobata* J. de C. Sow., an undescribed form of the same genus, and a new species of *Pseudomonotis*. At Dover, where a much greater bulk of material could be examined than at Brabourne, *Gryphaea bilobata* and the *Pseudomonotis* occurred very abundantly. The *Pseudomonotis* was more common in the highest beds and the *Gryphaea* at a rather lower level. Many fragments of a large belemnite accompanied the *Gryphaea*, but were not seen in the lowest beds. It is interesting to note that at Tilmanstone Colliery the same characteristic lamellibranchs have lately been found in the Kellaways Rock, and that the zonal ammonite *Sigaloceras calloviense* (J. Sow.) has also been obtained there.

Oxford Clay.

Again, the evidence obtained is furnished only by the two more easterly of our four localities. Overlying the Kellaways Beds the Ornatus Zone is well characterised by species of *Cosmoceras*—*C. castor* (Rein.), *C. duncani* (J. Sow.), *C. gulielmi* (J. Sow.), and perhaps also *C. jason* (Rein.). Regarding the numerous lamellibranchs found in this zone the great abundance of certain species of *Cucullaea* and *Grammatodon* is a noticeable feature. At Dover a basement bed was crowded with the shells of *Gryphaea*, and also contained *Belemnites oweni* Pratt. This bed may perhaps mark a period of locally slow accumulation on a current-swept floor while sedimentation was proceeding steadily

[1] *See* p. 136.

at Brabourne. The clay above the basement bed at Dover is identical lithologically with that of the much thicker Ornatus Beds at Brabourne, and the whole character of the fauna as well as the mode of preservation of the fossils is also in the closest agreement at the two localities. The palæontological evidence indicates that about 13 feet of beds may be ascribed to this zone at Dover and 60 feet at Brabourne.

At Tilmanstone Colliery the Hastings Beds rest directly upon a thin representative of the Ornatus Zone, and this basal part of the Oxford Clay shows the same lithological and palæontological characters as at Dover and Brabourne.

The overlying beds of the Oxford Clay have furnished forms of ammonites which permit a correlation with the Renggeri Beds of the Continent. Such are *Creniceras crenatum* (Brug.) and species of *Hecticoceras*, *Lunuloceras* and *Quenstedtoceras*, amongst others. *Alaria trifida* (Phill.) and several species of lamellibranchs also occur here. The 45 feet of beds assignable to this part of the Oxford Clay at Dover are found to be expanded to nearly twice this thickness at Brabourne.

The fauna of the uppermost zone, that of *Quenstedtoceras mariae*, is best represented at Dover, where it includes *Q. mariae* (d'Orb.) and other species referable to this genus, species of *Perisphinctes* and *Gryphaea*, as well as other forms. At Brabourne it was not possible to obtain such clear evidence, and the allocation of nearly 30 feet of strata to this zone rests principally upon the character of the fauna of the overlying and underlying beds. There is no perceptible disparity in the thickness of the Mariae Beds as observed at the two localities.

Corallian Series.

At a short distance above the top of the Oxford Clay, as we have defined it at Dover and Brabourne, there is palæontological evidence for the presence of the Cordatus Zone, characterised by species of *Cardioceras*, and it is found that the Cordatus fauna does not extend up through the whole thickness of the sediments, chiefly argillaceous, which lie between the Mariae Zone and the Corallian Limestone. The downward range of *Cardioceras* could not be accurately tested at Dover, because only part of the material from the lowest portion of the Corallian sequence was available for examination. *Cardioceras maltonense* (Y. and B.) was found there within 30 feet of the base; and at a lower level, close to the top of the Mariae Beds, there occurred a *Gryphaea* which shares the characters of massive habit and prolonged attached stage which are shown by degenerate forms of the *dilatata*-group in Lower Corallian beds elsewhere. The inward incrustation of the valves by other organisms is similar to that seen in the specimens of *Gryphaea* found in the Elsworth Rock, and indicates retarded sedimentation. The numerous specimens of *Gryphaea* found at Dover in the upper part of the Cordatus Beds and above this show the same characters of degeneration as are seen in the large examples from the Elsworth Rock and Ampthill Clay.

At Brabourne the lowest beds which we have assigned to the Corallian Series yielded *Peltoceras williamsoni* (Phill.), a species found in the Lower Calcareous Grit. Forms of *Cardioceras* occurred at a somewhat higher level and up to about 20 feet from the base of the Corallian Limestone. As estimated from the palæontological evidence the beds between the limestone and the top of the Oxford Clay are nearly 90 feet thick at Dover, and only about half this thickness at Brabourne. There can, however, be no certainty that the base of the limestone falls at precisely the same zonal level at the two localities. Nevertheless, the indications may be taken to show that this lower part of the series was less thickly developed at Brabourne than at Dover, and we thus see an exception to the conditions which are found to have prevailed so generally throughout the Jurassic strata of these two localities—that is, there was for a short time an easterly instead of a westerly augmentation of deposits.

The overlying Corallian Limestones have furnished an abundant fauna of Coral Rag facies. At Dover they were seen to be more purely calcareous in their upper part, where the fauna was distinguished from that of the lower beds chiefly by the great abundance of gasteropods, of which the most conspicuous and numerous were large forms of *Nerinea*. Here the corals are chiefly replaced by coarsely crystalline calcite; the most characteristic are species of *Isastraea*, *Thamnastraea* and *Thecosmilia*. In addition to *Nerinea* and allied gasteropods, there are species of *Bourguetia*, *Pseudomelania*, *Trochotoma*, *Trochus* and *Turbo*. Amongst the lamellibranchs one of the commonest is *Pecten vimineus* J. de C. Sow. The upper part of the series also yielded *Terebratula bauhini* Etall., not before recognised in this country, and *T. maltonensis* Oppel. *Cidaris florigemma* Phill. characterises nearly the whole thickness of the limestones, and *Hemicidaris intermedia* (Flem.) is also common. In the lower beds *Glypticus hieroglyphicus* (Goldf.) was found, and also *Ornithella delmontana* (Opp.), now recorded, we believe, for the first time in England. Near the base there occurred a band in which the large valves of *Pholadomya paucicosta* Roem. were numerous. The character of the fauna, as observed in the boring cores at Brabourne, did not differ materially from that seen at Dover, but a distinction between an upper and a lower series could not be established. The thickness of the limestones is about the same at both places.

The beds above the limestones are not well characterised palæontologically, and it is very difficult to draw a satisfactory line of demarcation between the Upper Corallian and Lower Kimmeridgian Series. The line we have chosen is somewhat arbitrary, but although situated above the millet-seed ironstone in a series of beds which contain a passage fauna, there are some points of palæontological distinction between the strata below and above. Below the dividing line the abundance of *Exogyra nana* (J. Sow.) and the occurrence of some clavellate *Trigoniae* gives a certain character to the relatively poor lamellibranch-fauna, but the assemblage here is chiefly contrasted with that of the Lower Kimmeridge Clay above by the absence of species which occur in those

beds. Some small striated valves of *Exogyra*, which may be looked upon as forerunners of *E. virgula* (Defr.), occur sporadically down to the ironstone, but were not accompanied by *Gervillia kimmeridgensis* d'Orb. and *Ostrea deltoidea* J. Sow. At the horizon of the ironstone at Dover there were found spines of *Cidaris smithi* Wright and a degenerate perisphinctoid ammonite of an undescribed genus. In rather lower beds occurred *Belemnites nitidus* Dollf. [*non* Phill.]. The strata at about the level of the ironstone may be correlated with the so-called " Kimmeridge Grit " near Weymouth. We have assigned nearly 100 feet of beds to the uppermost subdivision of the Corallian Series at Dover, and about 160 feet at Brabourne.

Kimmeridge Clay.

This formation is present in all the four sections studied, but is so unequally represented that it has been necessary to pay particular attention to the palæontological characters shown in the different parts of the sequence in order to elucidate the correlation. At Dover only the Lower Kimmeridge Clay is present, and a study of the fossils shows that this subdivision is not complete in its upper part at this locality. The remnant is immediately overlain by the Hastings Sands. We have referred to the Lower Kimmeridge Clay in these Kentish sections as the Virgula Beds, because of the distribution of *Exogyra virgula* throughout its whole thickness. Specimens are much less numerously present near the base, and are of smaller dimensions than the large and typical examples which occur in abundance towards the top. Only some upper portion of our Virgula Beds is to be correlated with the Virgulien of Pellat's classification for the corresponding strata in the Boulonnais. At Brabourne all the Virgula Beds are present, and this is the case at Pluckley also, but it is not quite certain whether the boring at the latter locality passed through the actual base. *Ostrea deltoidea* J. Sow. occurred near the base at Dover and Brabourne, while *Gervillia kimmeridgensis* d'Orb. and *Nucula menkei* Roem. were characteristic of the lower half of this subdivision. *Physodoceras orthocera* (d'Orb.), the leading ammonite for the Orthocera Zone of the Continent, was found near the base at Brabourne. In the upper beds at this locality, which represent a horizon higher than any seen at Dover, *Astarte ingenua* de Lor., *Protocardia morinica* (de Lor.) and *Trigonia* cf. *pellati* Mun.-Chalm. are some of the species which were not met with either at Dover or in the lower beds at Brabourne.

The incomplete Lower Kimmeridge Clay at Dover is only 45 feet thick, and it may be estimated that the strata which actually correspond at Brabourne are about three times this thickness. We believe that the uppermost 60 feet of the Virgula Beds at that place occupy a higher position in the sequence than any of the clay at Dover. The total thickness of the complete Lower Kimmeridge Beds at Brabourne is about 200 feet, while at Pluckley it has expanded to upwards of 300 feet.

The Upper Kimmeridge Clay, passed through at Brabourne, Pluckley, and Penshurst, is characterised by a different assemblage of fossils. The upward distribution of *Exogyra virgula*

terminates abruptly at the base of this subdivision, and the leading lamellibranch which immediately takes its place is *Modiola autissiodorensis* (Cott.). These upper beds are incomplete in their upper part at Brabourne, where a considerable part of the sequence is cut out by an unconformity, but they are completely represented at Pluckley, and very nearly, if not entirely so, at Penshurst. We estimate on palæontological grounds that the 65 feet of Upper Clays at Brabourne are represented by at least 370 feet of beds in the much expanded series at Penshurst. This part of the sequence contains a distinctive assemblage of fossils. In addition to the above-named lamellibranch there are *Orbiculoidea latissima* (J. Sow.); *Astarte* cf. *mysis* d'Orb. and other small ornate species of that genus; a *Cyprina*, designated species (A) in our lists; *Lucina minuscula* Blake; *Protocardia morinica* (de Lor.); *Aporrhais* cf. *pietteı* (Buv.); and "*Holcostephani*," resembling *H. pallasianus* (d'Orb.), these ammonites coming in at some distance above the base. The little radial plates of the free-swimming crinoid *Saccocoma* were found at Penshurst at a depth of about 1,800 feet. The westerly augmentation of sediments is very strongly marked, for the complete Upper Clays, which are about 190 feet thick at Pluckley, are at least 620 feet thick at Penshurst, where the boring did not reach the Virgula Beds and possibly did not penetrate quite to the base of the Upper Clays.

The highest portion of the Upper Clays, occupying a higher position in the sequence than any of the beds preserved at Brabourne, could be best studied at Penshurst, where there is conformity with the overlying Portland Beds. Here were found a number of fossils which were not seen to occur at lower levels. Such were *Cyprina implicata* de Lor.; a very distinctive *Grammatodon*, bearing some resemblance to *G. rhomboidalis* (Cont.); various species of "*Holcostephanus*," including large forms comparable with *H. giganteus* (d'Orb.) in the highest beds; and species of *Perisphinctes* showing marked polyplocoid degeneration. The mutation of *Modiola autissiodorensis* found in the highest part of the series is smaller and shorter than that seen in the lowest beds.

We conclude, on palæontological grounds, that the top of our Upper Kimmeridge Clay corresponds with the top of the Portland Sands in Dorset, and it is evident that in Kent the deeper water argillaceous conditions persisted during the time when in some other parts of the country there was an impure and sandy facies connected with shallowing, towards the close of the Kimmeridgian epoch. Hence we have classified no part of the Kentish series as Portland Sand.

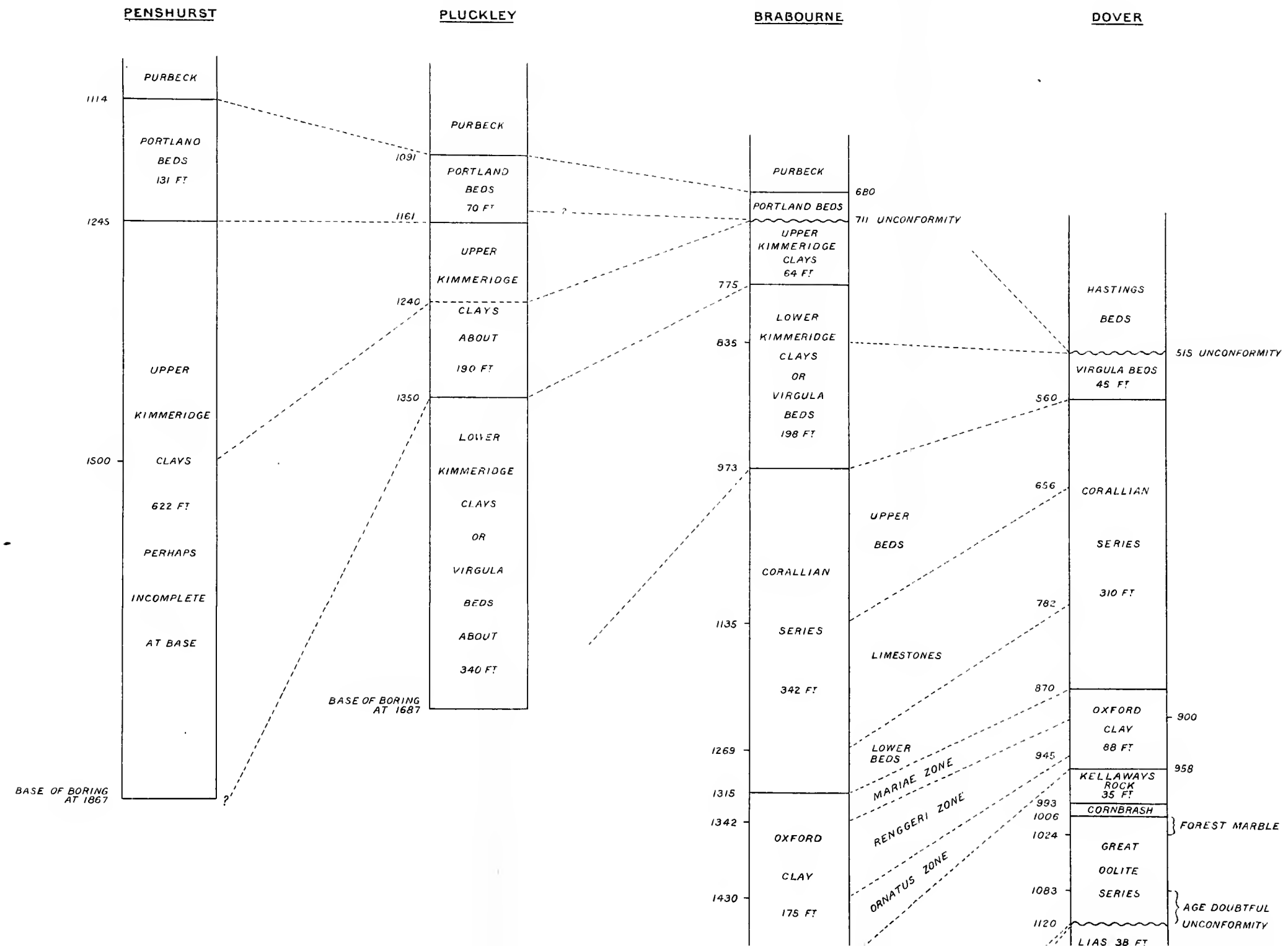
Portland Beds.

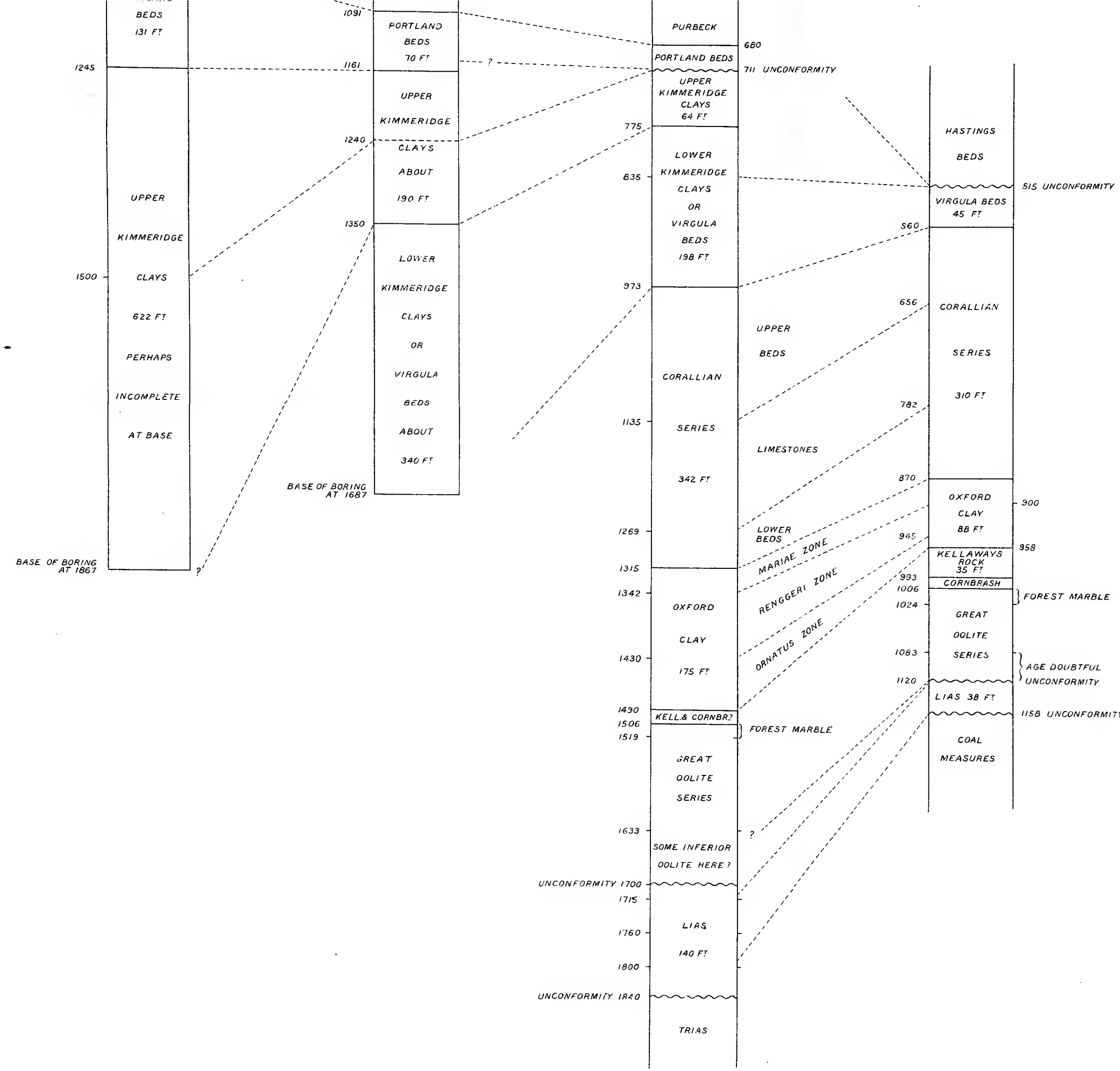
These rocks, which are to be correlated with the Upper Portland Beds of Dorset, could be studied at Brabourne, Pluckley, and Penshurst. It is not improbable that some small thickness of the basal part may be absent at Brabourne. In the lower part of this series the remains of large "*Holcostephani*" were found to occur, comparable with *H. bononiensis* (de Lor.) [Blake's interpretation]

Diagram to Illustrate the Correlation of the Marine Jurassic Strata.

Vertical Scale : 1 inch = about 125 feet.

The figures at the sides of the columns represent the depths in feet from the surface.




BEDS
131 FT
1245
UPPER
KIMMERIDGE
CLAYS
1500
622 FT
PERHAPS
INCOMPLETE
AT BASE
BASE OF BORING
AT 1867
?
1091
PORTLAND
BEDS
70 FT
1161
UPPER
KIMMERIDGE
CLAYS
1240
ABOUT
190 FT
1350
LOWER
KIMMERIDGE
CLAYS
OR
VIRGULA
BEDS
ABOUT
340 FT
BASE OF BORING
AT 1687
PURBECK
680
PORTLAND BEDS
711 UNCONFORMITY
UPPER
KIMMERIDGE
CLAYS
64 FT
775
LOWER
KIMMERIDGE
CLAYS
OR
VIRGULA
BEDS
198 FT
835
973
CORALLIAN
SERIES
342 FT
1135
1269
1315
1342
OXFORD
CLAY
175 FT
1430
1490
1506
1519
KELL.& CORNBR.?
FOREST MARBLE
GREAT
OOLITE
SERIES
1633
SOME INFERIOR
OOLITE HERE ?
UNCONFORMITY 1700
1715
LIAS
1760
140 FT
1800
UNCONFORMITY 1840
TRIAS
?
UPPER
BEDS
LIMESTONES
LOWER
BEDS
MARIAE ZONE
RENGGERI ZONE
ORNATUS ZONE
656
782
870
945
993
1006
1024
1083
1120
HASTINGS
BEDS
515 UNCONFORMITY
VIRGULA BEDS
45 FT
560
CORALLIAN
SERIES
310 FT
OXFORD
CLAY
88 FT
900
KELLAWAYS
ROCK
35 FT
958
CORNBRASH
FOREST MARBLE
GREAT
OOLITE
SERIES
AGE DOUBTFUL
UNCONFORMITY
LIAS 38 FT
IISB UNCONFORMITY
COAL
MEASURES

and *H. giganteus* (d'Orb.) [*non* Sow.], while the familiar *Modiola autissiodorensis* of the Upper Kimmeridge Clay is here absent. Higher in the series were found typical lamellibranchs of the Portland Stone Series, *Trigonia gibbosa* J. Sow., *Trigonia* cf. *carrei* Mun.-Chalm. and *Pecten lamellosus* J. Sow.

Purbeck Beds.

These rocks were present in all our sections except Dover. The abrupt transition from purely marine to purely fresh-water conditions at the top of the Portland Beds could be best observed at Penshurst. The Purbeck rocks of Kent have yielded numerous remains of typical fresh-water forms such as are already known in the corresponding strata in Dorset. These include species of *Cyrena*, *Unio* and *Viviparus*, and at some levels abundant ostracods —for example, *Darwinula leguminella* (Forbes), *Cypridea punctata* (Forbes) and *Cypris purbeckensis* Forbes. About the middle of the series the occurrence of such fossils as *Corbula alata* J. de C. Sow., *Gervillia* (possibly *G. arenaria* Roem.), *Modiola*, *Ostrea distorta* J. de C. Sow., *Protocardia purbeckensis* (de Lor.) and other species of *Protocardia*, gives clear indications of the influence of a marine incursion producing brackish conditions, just as in the Middle Purbeck rocks of Dorset. The upper limit of the Purbeck Beds could not be fixed on palæontological grounds.

Wealden Series.

Few fossils were recovered from the Hastings Beds, which were penetrated in all the four sections. At Dover occasional ostracods, fragments of fish and indeterminable relics of plant-life were the principal remains seen, and in the pebbly beds there were a few fragments of the bones of saurians. At Brabourne and Penshurst some few remains were recovered from the borings. In addition to cyprids, *Estheria subquadrata* (J. de C. Sow.), which is elsewhere only found in the Hastings Beds, occurred at Penshurst. Amongst the fragments of plants *Onychiopsis mantelli* (Brongn.) was recognised from Brabourne, *Sphenopteris fittoni?* Seward and *Cycadites saportae* Seward from Pluckley, and *Leckenbya valdensis* Seward from Penshurst.

The Weald Clay, which was seen only at Dover, Brabourne and Pluckley, yielded a typical assemblage of forms. *Weichselia mantelli* (Brongn.) was the only determinable plant found. Amongst the molluscs were species of *Cyrena*, *Unio* and *Viviparus*; amongst the ostracods *Cypridea* and *Metacypris*; and the recognisable fragments of fishes were referable to *Acrodus*, *Hybodus* and *Lepidotus*. Many of the fossils were crushed and ill-preserved, and, as usual in the strata of this series, some of the bedding-surfaces showed innumerable individuals belonging to one or two species only. The specimens obtained from these sections were relatively so few in number, and the vertical distribution of the different species within the Weald Clay is so little known, that we are unable to give any useful indications of the manner in which these fossils may serve to characterise different parts of

the series. There was no doubt great local variability of conditions, and there is the further difficulty that evolutionary progress and differentiation was very slow amongst the invertebrates of this, as of other fresh-water series.

Atherfield Clay.

Although this member of the Lower Greensand was penetrated at Dover and at Brabourne, it was only possible to make a study of its palæontological features at the former locality, where the 43 feet or so of clay was found to be richly fossiliferous. The great majority of the specimens seen are lamellibranchs, and with the notable exception of *Anomia*, *Exogyra* and *Pecten*, these are for the most part preserved as casts of the interior upon which have become impressed the most delicate markings of the external surface of the valves. In the lowest 15 feet of beds the fossils were most thickly clustered, and here occurred very numerously *Pinna robinaldina* d'Orb. In all, upwards of 60 species of fossils were collected, and many of these are also found in the Perna Bed, Atherfield Clay and Crackers of the Isle of Wight. It was not possible to recognise corresponding subdivisions at Dover, and no trace was seen of the large species of *Perna* which occur in the Perna Bed of Atherfield.

The cephalopod remains include an *Acanthoceras* closely resembling *A. albrechti-austriae* Uhlig, which occurs in Aptian Beds in Silesia and North Germany, *Hoplites deshayesi* (Leym.) and *H. laeviusculus* von Koenen. *Hoplites deshayesi*, one of the most characteristic of the Continental Aptian ammonites, was found distributed at Dover through the whole thickness of the clay.

The basement bed yielded some fragmentary fish-remains, referable to *Acrodus* and *Hybodus*, which are probably derived fossils from the underlying Weald Clay.

Sandgate Beds.

Our knowledge of the palæontology of the Sandgate Beds is relatively scanty, and the state of preservation of the molluscan remains found at Dover and Brabourne rendered the collection of specimens a difficult matter. No determinable cephalopods were seen. At Dover the lamellibranchs included specimens of *Astarte* (*Eriphyla*) which we have referred to *A. concinna* J. de C. Sow. and *A. striata* J. de C. Sow., both of which are species of the Blackdown Beds. Relations with the molluscan fauna of Gault times, which became more strongly marked in the Mammillatus Bed, are thus already faintly foreshadowed. Other interesting lamellibranchs are undescribed species of *Meretrix* [*sensu lato*], which do not appear to fall into any of the narrower generic groups which have recently been recognised to occur in the Cretaceous rocks of this country.

The basement bed illustrates well the work of lamellibranchs which bored into the underlying floor of Atherfield Clay (Plate I.). At least two species appear to have been engaged in making the very numerous burrows which produce such a singular interlocking

between the greensand at the base of the Sandgate Beds and the fine-grained strongly-contrasted Atherfield Clay below. The most numerous of these borers is a new species of *Pholadidea*, but occasionally an individual of *Panopea mandibula* (J. Sow.) was found in the position of life occupying a sharply cut crypt quite similar to those bored out by the *Pholadidea*. The basement bed also yielded large examples of *Pecten orbicularis* J. Sow.

At Brabourne a light green loam ascribed to the Sandgate Beds yielded a few brachiopods and molluscs. The only determinable species were *Gervillia forbesiana* d'Orb. and *Pecten* (*Neithia*) *morrisi* (Pict. and Ren.).

Folkestone Beds and the Mammillatus Bed.

Fossils from this part of the series could only be obtained at Dover. Some few traces of Mollusca were seen in the Folkestone Beds, but they were quite insufficient to show the nature of the fauna.

The Mammillatus Bed yielded a few brachiopods and numerous internal casts of Mollusca. The character of the fauna agrees exactly with that observed in the same bed near Folkestone. The ammonites most numerously represented are *Douvilleiceras mammillatum* (Schloth.) and a *Desmoceras* which closely resembles *D. beudanti* (Brongn.) of the overlying Gault Clay, differing from it chiefly by a rather more strongly fretted septal suture and by the constant presence of weakly sigmoidal constrictions. A specimen of a strongly ornamented species of *Hoplites* [*sensu stricto*] helps to illustrate the introduction of a generic group which attained such a rich development in the Gault Clay. Species of *Cucullaea*, *Cyprina*, *Nucula* and *Plicatula* which occur here, are found also in the Gault Clay, and lend a character to the fauna by which an approximation to that of the overlying beds becomes strongly indicated.

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ONE-INCH MAP, OLD SERIES (1 inch to the mile, or 1 to 63360).

Nos. 1 to 110, which have not yet been replaced by New Series Maps, are issued as whole sheets and quarter-sheets, hand-coloured, in either a "Solid" or a "Drift" edition, or in both. For Memoirs on Old Series Maps, *see* below.

SIX-INCH MAP (6 inches to the mile or 1 to 10560).

Parts of the Six Northern Counties were published on the six-inch scale prior to 1880. Large parts of the Coalfields of South Wales, North Staffordshire, Leicestershire, Derbyshire and Nottinghamshire, and the Mining District of Cornwall, have been published on that scale since 1903. Sheets published since 1903 can be procured with the Geological lines, uncoloured 1*s.* 6*d.* each quarter-sheet, or coloured, at the cost of colouring. Some are issued in both a "Drift" and "Solid" edition.

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HORIZONTAL SECTIONS.	VERTICAL SECTIONS.
1 to 140, 146 to 148.	1 to 88.

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